Calcium's behavior in hydroponics

Calcium is often one of the most puzzling elements in hydroponic culture due to its ability to respond fairly non-linearly to nutrient concentrations in solution. This behavior is the result of its transport dynamics and its relationship to other elements that may antagonize it very effectively when they reach higher concentrations. On today's post I will talk about calcium behavior in hydroponics and how we can play with both environmental and chemical properties to change its concentration in leaf tissue.



A leaf showing symptoms of a calcium deficiency. This is usually NOT caused by a lack of calcium in the nutrient solution.

Imagine you've had a good growing season up until now, your plants are looking great, you've been doing everything properly. Suddenly, you start to see what appears to be a calcium deficiency on your leaves. You proceed to analyze your tissue and notice that your Ca levels are way below what you expect, yet your nutrient solution seems to be very Ca rich, at almost 150-200 ppm. You panic and increase the Ca level to 250 ppm, your following test results come out even lower.

You're not alone, you've just misunderstood calcium transport.

Most calcium deficiencies are actually not the result of Ca missing in nutrient solutions but they are caused by faulty Ca transport, which is often related with environmental issues. Calcium transport depends substantially on transpiration, so the solution to Ca deficiencies can be as simple as increasing your vapor pressure deficit (VPD). Ca is also absorbed more effectively when its at a lower concentration than at a higher one, so often increasing Ca will decrease its transport to leaf tissue. This study on tulips and its bibliography illustrates this fairly well, the increase in tissue with Ca follows a parabolic trajectory, where the largest Ca concentrations actually lead to lower Ca in tissue. You can push Ca to the leaves with higher VPD though, as this paper on Ca fortified lettuce shows, with the lettuce grown at Ca at 300ppm at 28C showing the highest Ca accumulation.

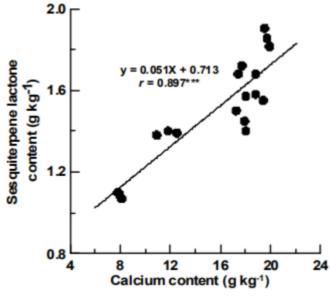


Fig. 1: Relationship between sesquiterpene lactone content and calcium content in the flower of *C. coronarium* L.

Taken from <u>this article</u>. It shows that terpenes can increase at larger Ca content in tissue in some flowering plants.

At lower levels Ca can actually start to show the inverse behavior and start to accumulate very heavily in tissue as its transport can become extremely favorable. If you notice a VPD then you might actually want to increase Ca in solution rather than decrease it, as an increased concentration in solution might actually make transport less favorable. However the most determinant factor in Ca absorption is water transport, so this excessive Ca might just be indicating you that your VPD is too high (so reduce temperature or increase your relative humidity).

This big influence of VPD explains why results of ideal Ca concentrations and Ca:K ratios are significantly disperse in the scientific literature. A recent paper for strawberries shows this ideal ratio to be around 1.3-1.4 but some papers (like the one on tulips shown before or this one) has it way closer to 1.0. The ideal ratio for your crop will also be dependent on the water transport your plants are forced to assume due to your ambient conditions so you will likely need to optimize this variable for your particular growing conditions.

A good place to start for flowering plants in terms of K:Ca is usually a ratio of around 1.2 however, you will need to do tissue analysis to figure out whether the Ca absorption is at the ideal point or whether you want to increase/decrease your Ca. Just bear in mind that increasing Ca in solution might reduce it in your leaf tissue so to reduce Ca in tissue try to play with your VPD first before you play with the concentrations in solution. Chances are that if you're getting too much or too little your issue is that you're too deviated from your ideal VPD situation.

Better understanding pH dynamics in hydroponic culture

Plants require specific conditions within their root zones to give optimal yields. The negative of the logarithm of hydronium concentration (a.k.a pH) is a very important measurement that tells us if the root zone is too acidic or too basic for our plants. However pH is affected by many different variables, making the calculation, theoretical understanding and modification of this variable difficult — and often very puzzling — for a significant percentage of growers. Today I want to go into how we can understand these pH changes from a qualitative perspective to get an idea of how pH can be expected to change in solution if we modify one variable within our hydroponic crop.



The final pH in the root zone of a hydroponic crop will mainly depend on the following factors: Chemical species in solution, plant absorption/secretion and media reactions. Basically we need to consider the chemistry of the solution, the way plants absorb nutrients and the chemistry of the media. The size of these effects relative to one another is also very important to consider.

In a normal hydroponic crop with a nitrate rich solution plants will tend to absorb more nitrate than any other ion, which will tend to increase pH as plants will excrete bases when they take anions in. Since the effect of nitrate in pH is very small the net effect is a substantial increase in the pH of the nutrient solution. Anions like citrate can also cause increases in nutrient solution pH due to a similar reason, they can be strongly taken in by plants and generate upside drifts.

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Model of a citrate ion molecule.

The effect of anion absorption can be offset by acids present in solution. Phosphorus is most commonly present in hydroponics at a pH of 5.8-6.2 as H2PO4(-) which is a weak acid that is able to react with the bases excreted by plants. This means that higher P containing solutions will tend to drift less towards the upside than solutions that contain more P. This is a common reason why yields are usually better for less experienced growers when higher P solutions are used, because they are more forgiving to pH drifts due to their higher buffering capacity towards the upside at the pH used in hydroponics. When we add P the effect of the buffer is way bigger than the effect of P absorption, as P is not absorbed in very high concentrations by plants.

When you increase or decrease the concentration of an ion in solution you need to consider if it will be absorbed, how strong its absorption will be relative to other ions and how this relates to the chemistry of this ion in solution. For example citrate provides a relatively strong buffer towards both upside and downside moves at a pH of 5.8-6.2 but its absorption by plants negates this effect and generates a net drift towards the upside in solution in most cases.

Species that are not absorbed so significantly — like bicarbonate ions — are better at buffering moves towards the

upside, since they provide a weak acid to react with plant secretions without providing a very significant source of anions for the plant to absorb and exchange for more basic species.

This exact same logic can be applied to positive ions that are easily absorbed by plants. Adding ammonium generally causes strong decreases in the pH due to plants exchanging ammonium with hydronium ions. However this effect can be compensated by adding things that cause upside drifts either through absorption or through buffering effects. Adding ammonium citrate to a nutrient solution causes a rather balanced effect due to both the ammonium and citrate absorption/buffering compensating.

The media is also very important to consider as non-neutral behavior will tend to strongly drift pH due to the mass of the media within the hydroponic setup. To prevent this problem it is not uncommon to treat media with a buffer before use, although this can become prohibitively expensive quickly if large volumes of media are used. It is more common to deal with the quirks of the media using nutrient solution chemistry. To get an idea of how your media affects pH you can let your media soak in nutrient solution and notice how pH evolves as a function of time. If the pH increases or decreases you'll get an idea of what you should expect and the think about how you might want to handle it.

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Peat moss

Media that decompose — particularly peat moss — will tend to acidify and become more and more acidic with time. This effect can be so strong that the only reliable solution is to amend with some low solubility base that can offset this effect with time (such as limestone). This is however problematic since the base will tend to run out towards the flowering stages of crops, where its help is most needed to offset potassium

absorption. For this reason it's usually more manageable to use a media like coco coir, which has a more stable pH profile and will not tend to "fight growers" through the crop cycle.

As you can see pH in hydroponics can be a complicated issue. When it starts to drift you need to immediately think about what the source of the ions is. If the pH increases you have a contribution of basic ions that exceeds the strength of the weak acids in solution, while the exact opposite is the case if the pH decreases. What is the source of these ions? Is the plant absorbing more of something? Do we need to add something to counter the effect? Is the media the culprit? Start asking and trying to answer these questions and it will become easier to understand why your pH is drifting and what you might be able to do about it.

Five important things you should know about humidity in hydroponics

Humidity is one of the most important metrics in hydroponic culture. In order to have a successful crop it is critical to understand what humidity actually is, how we measure it, why we need to control it and where we want it to be. Today I want to share with you five things you should know about humidity in hydroponics. These pointers should be equally useful to newer growers and those who want to get even higher performance out of their current hydroponic crops.



There is a big difference between relative humidity and absolute humidity. Although we generally understand humidity as the amounts of water in the air in reality what we usually measure in hydroponics is "relative humidity" (RH) which does not measure how much water there is in the air but what percentage of the available capacity we are using. A measure of 70% tells you that the air currently holds 70% of the water it could hold, but it doesn't tell you anything about how much water there actually is in the air. Absolute humidity, on the other hand, tells you how much water you actually have in the air. As warmer air can carry significantly more water it is important to realize that a 70% humidity at 80F implies there is way more water in the air than a 70% humidity measurement at 50F.

Relative humidity meters are not reliable instruments. We often buy instruments to monitor ambient conditions without much thought about how they work or how good or bad they are. Relative humidity is a tricky measurement and cheap, semiconductor based relative humidity meters have not been very reliable or accurate. Usually a humidity meter will have an error of +/- 5% and it's accuracy will not be on point if it has been exposed to very high humidity values (if there was ever any condensation on the sensor it probably was damaged to a significant extent). I often recommend buying at least 3 instruments with different chipsets. Having just one — or even several meters with the exact same chip — can be a recipe for

disaster. The chipsets below are setting a new standard for precision and accuracy, so I would recommend you give sensors with those a try if you're looking for more accurate RH measurements.

Company	Humirel	Sensirion SHT21	
Part Number	HTU21D		
Product	THE WAST		
Humidity Accuracy	±2%RH	±2%RH	
Temperature Accuracy	±0.3℃	±0.3℃	
Operating Range	0—100%RH	0-100%RH	
Power Supply	1.5—3.6V	2.1—3.6V	
Interface	12C	I2C	
Power Consumption	400uA	300uA	
Response Time	5s	8s	
Package	3x3mm DFN	3x3mm DFN	

It is often better to go over than to go under. Although higher or lower relative humidity values are both sub-optimal for plants, it is often better to go with higher humidities rather than lower humidities in terms of crop yields. Lower RH values will tend to stress plants more — especially if the temperature is high — while higher RH values are often easier to deal with for tropical plants (which are the kind we often grow in hydroponics). Although higher humidity can definitely cause important issues — such as fungal diseases — we have ways to deal with this that are more effective than our ways to deal with stress caused by low relative humidity. Of course extreme values will be very detrimental to plants either way, so when I say high consider I don't mean 95% RH at 80F.

Relative humidity can change a lot depending where you measure it. It is important to place RH meters at different places that represent what the plant is actually being exposed to. If you place RH meters in a greenhouse, far away from plant canopy, you will get a very poor representation of what the

plant is actually experiencing and you might try to increase humidity substantially when this might not be needed. Ventilation is critical to alleviate this issue but in order to stay on top of it I always advice having meters within plant canopies in order to know for a fact how much your humidity values diverge between different places in your growing environment. Humidity is always bound to be higher closer to plants — as they transpire — but we should know how different it is. A big difference is a strong hint that there is not enough ventilation around the plants.

Humidifiers are often needed during the winter. Most crops that grow in warehouses during winter times require humidifiers, since the plants often do not evaporate enough water to compensate for the complete lack of water within the dry winter air (this is specially true if the volume of the growing warehouse is large). If you want to have a successful crop during winter times it will be paramount for you to have adequate humidifiers to ensure that your RH values are within what's ideal for your plants. Depending on the size of your crop this might require significant planning and investing so make sure you always consider this when designing your winter growing cycles.

I hope you have found the above pointers useful. There are certainly many other important aspects of humidity, such as relative humidity meter calibration, judging ideal humidity using vapor pressure charts, or ensuring that plants have enough defenses if they happen to get exposed to exceedingly high humidity levels within their canopy. We will certainly discuss some more of these within future posts!

DIY Warm white LED lamp PAR measurements, not so exciting after all!

If you read my last few posts about DIY LED lamps built using 150W warm white LED cobs (which do not require an independent driver) you might have been excited by some of my claims. I previously stated that you could probably get around a 1000W HPS equivalent using just two of these lamps, which meant an energy saving of around 60% relative to the HPS equivalent. However to really verify these claims I wanted to get new PAR and lux meters to perform proper PAR and lux measurements. The results my friends, are disappointing.



Previously I thought that these lamps were close to half of an HPS equivalent based on initial lux measurements. At the same distances, directly below the lamp, I could get around half the lux equivalent of your average HPS lamp, I thought from the warmer spectra of these white warm cobs that the PAR contribution would be significantly higher than that of a regular HPS but it seems that — due to the inefficient use of a white phosphor to produce the spectra — basically the PAR efficiency is equal to that of an HPS lamp.

The PAR (Photo-synthetically Active Radiation) basically measures the number of photons that can be used in

photosynthesis that you get per square meter per second off a given light source. I will write a more in-depth post about PAR in the future, but it basically tells you the plant-usable photon flux you get. It is therefore measured in umol*s⁻¹*m⁻².



I performed classic PAR measurements with a 150W lamp 15 inches above a target center with measuring points around a 4 square feet area (to compare with the variety of HPS measurements you can find here). The results, in the first image in this post, show you the map of PAR values across the 2 feet by 2 feet area. This shows that the lamp is basically giving you 1466 umol*s⁻¹*m⁻² per 1000W at its highest point, which is below the PAR/watt of even the poorest HPS models. With this lamp model using 150W cobs you will therefore need at least 7 lamps to reach the same equivalent of a 1000W HPS in terms of actual photo-synthetically active radiation.

Not only that but without any focusing or dispersing elements the PAR decay as a function of light distance is much more dramatic than for regular, reflector mounted HPS lights. With all these information it now seems clear that these warm white light LED cobs are NOT a good HPS replacement.

However the idea of the zip tie lamp is not dead! I found out that there are actually "full spectrum" LED cobs that are

specifically designed to be grow lights (so basically a combinations of red and blue LED lights). These cobs come in 20, 30 and 50W formats and they should have a much more favorable PAR than the 150W warm white LED cobs. I have now ordered some of these cobs (here) to rebuild my zip tie lamp and see if I can indeed get a much better PAR/watt and watt/dollar compared with normal HPS lights.

Cheap DIY high power LED grow lights: Introducing the Zip-tie lamp

Make sure you also read <u>this post</u>, where I studied the PAR of these lamps and realized they are not as good as I thought!

Several months ago <u>I wrote a post</u> about using high power LED cobs that do not require an external driver in order to build a high power DIY LED lamp. However I hadn't built a practical lamp using these cobs at that particular point in time so I just gave a general idea of why I would use these diodes and how the particular lamp setup would work. Today I want to talk about how to build one of these lamps in practice using an aluminum heat sink, a 150W warm white LED cob, a fan and some zip ties. The setup lacks the use of any adhesives and should provide you with roughly a 40-50% equivalent of a 1000W HPS. With two of these lamps you should be able to run the equivalent setup to 80-100% of a 1000W HPS in terms of PAR with around 60% less power consumption.



The idea of this post is to help you build a very affordable DIY lamp. However please note that this lamp involves work with mains voltages which are dangerous. Please familiarize yourself with all the precautions needed when working with high voltages. All the information herein in is provided as-is for educational purposes with absolutely no guarantee, either expressed or implied.

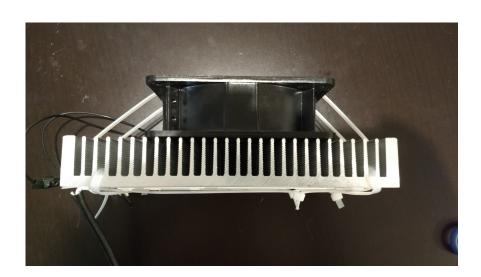
To build this lamp — showed above — you will need these materials (note that if your country uses another voltage you will need to buy the appropriate pieces for the voltage in your country):

- Warm white 150W LED cob
- 200x60x30mm aluminium heat sink (2 needed)
- 110V-120V AC fan
- Nylon zip ties 30cm
- Cable and wall connector
- Thermal compound (optional)

Initially I wanted to build a lamp using a high power warm white LED cob by gluing the cob to the heatsinks using a thermally conductive glue. However the problem with this is that these glues very permanently bind the cob to the heatsink so if for any reason the cob fails you would lose the heatsinks because the cob would be bound to them. For this reason I decided to use zip ties instead, which provide an

easy way to secure the entire ensemble and allow you to easily replace any failing part rather quickly. I used nylon zip ties but you can also use stainless still ones if you want the setup to be more resilient (although things will be harder to cut if you make a mistake).

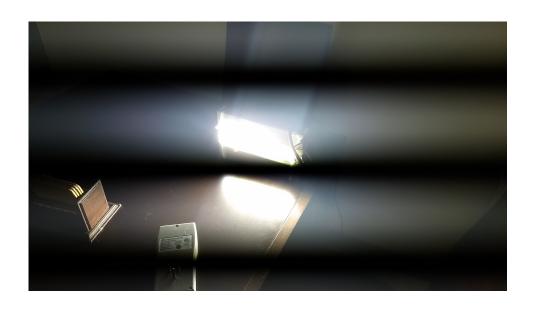
To assemble the lamp I basically used 4 zip tie lines two horizontal and two vertical. For the lines that go the width of the heat sink I just had to use one zip tie but for the other two lines — that also go above the fan — I had to use two zip ties for each line (you can connect one zip tie to another to have a larger zip tie). You need to tighten the zip tie very hard to ensure the cob is in direct contact with the aluminum along all its length, you can also use some thermal compound (like the one you use for CPUs) between the cob and the aluminum heat sink for maximum heat transfer. The pictures below show you a bit better how I performed the entire assembly. When putting the fan on top of the heat sinks make sure the airflow is towards the heatsink (flow arrow in the case pointing down) and that the fan can spin freely).





Finally I connected the cob directly to the AC line by soldering the appropriate live/neutral cables to the connectors at the left size of the cob (in the above picture). I then covered the soldered spots with silicon glue to ensure that the connections were as electrically isolated as possible. Make sure you solder as small portion of wire as possible and make sure the wire makes absolutely no contact with the aluminum heat sink or you will have a short. I also soldered the fan cables to the live/neutral as well since the fan can be driven directly by AC as well.

Since you have the zip ties you can also use them to hang the lamp, you can also add screws to the fan screwing ports and use those to hang the lamp from the ceiling. When I turned on this lamp its power consumption was around 220W — measured directly from the wall — meaning that it consumed a bit more power than what was advertised (which is not uncommon for these cobs). Since my voltage is a bit higher than 110V — which is the minimum rating for this cob — I actually get a slightly higher light/heat output than someone using it at a lower voltage. The fan — which takes around 12-15W on its own, also contributes to this consumption level.



When you power on this lamp — image above (sorry about the camera not being able to handle the light intensity) - you'll immediately notice how the heat sink starts to heat up. I have tested the lamp through 2 hours of continuous operation up until now and the heat sink reached a stable temperature of around the 120°C (~ 250F), the final temperature you reach will of course depend on your ambient temperature and how well you assemble the components. It is however very important for you to test each one of these lamps for 12/24 hours to ensure that they don't heat up excessively. Nylon will melt at around 220°C so you definitely don't want your lamp to ever reach even close to that temperature (to be safer you can use stainless steel zip ties). However it is very likely that the LEDs will burn out way before this happens if your temperature rises too far. You can also add a second fan or use a larger heat sink if your temperature is too high.

In the end the setup is extremely simple to build and you can get roughly 40-50% of a 1000W HPS with one of these lamps. With two of these lamps you will run at around 450W which is 55% less power than an equivalent HPS setup. Although heat generation is no joke here, it is indeed much less than the comparable heat output of a 1000W HPS. With a cost of less than 80 USD per lamp you will be able to build these lamps at a far lower cost than the very expensive grow lights you can get online (which can often go for thousands of dollars for a

single 1000W HPS equivalent). If you read my earlier post you will notice that I previously thought you needed 4 cobs to reach the equivalent of a 1000W HPS, turns out you only need two 110V cobs running at 120V!

I have made some PAR, lux and temperature measurements but I want to keep those for a future post where we will look at some of the spectral and thermal characteristics of this lamp vs other lamp types.

Potassium concentration and yields in flowering plants

From the different nutrients that are needed by plants we have known for more than 4 decades that potassium is of critical importance to flowering/fruiting plants. Potassium is one of the most highly limited nutrients in soil due to its high mobility and great increases in yields have been achieved with both potassium fertilization in soil and the use of properly balanced nutrient solutions containing enough potassium in hydroponics. But how important is potassium and what is its ideal concentration in hydroponic nutrient solutions when growing flowering plants? Today we are going to take a look at the scientific literature about potassium and what the optimum levels of potassium for different flowering plants might be in order to maximize yields.

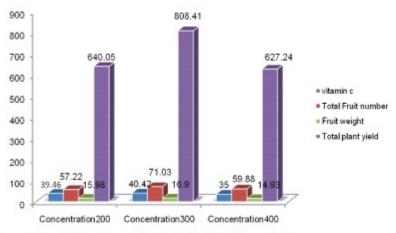


Fig. 1: Effect of potassium concentrations on quality traits in strawberry cultivars.

There are many studies in the scientific literature dealing with the effect of potassium on various flowering plants. Earlier evidence from the 1980s pointed to optimum concentrations of potassium being close to the 160-200 ppm range. The book "mineral nutrition" by P.Adams (here) summarizes a lot of the knowledge that was available at the time and shows that for the growing techniques available at the time using greater concentrations of K was probably not going to give a lot of additional benefit.

However newer evidence from experiments carried out within the past 10 years shows that optimum potassium concentration might depend on a significant variety of factors, from which media, other nutrient concentrations and growing system type might play critical roles. For example study on strawberries in 2012 (here) showed optimum concentrations of K to be around 300 ppm for strawberries and the optimum media to be a mixture of peat+sand+perlite (image from this article included above).

Table 3: Effect of cultivar on yield of tomato and ascorbic acid concentration in

Cultivar	Yield (kg/plant)	Ascorbic acid (mg/100 g FW)
Avinash-2	2.00a ^a	25.69a
Pant T-3	1.74b	22.80b

°Values in a column followed by the same letter are not significantly different, $P \leq 0.05$, Fisher's LSD.

Yield over Cultivar

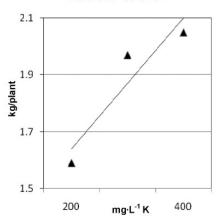


Figure 3: Yield, pooled over cultivars as affected by supplied K concentration. The regression was Y = 0.0024 (X) + 1.1733 (R², 0.871).

Evidence from experiments on tomatoes (<u>link here</u> and image from this article above) also shows that for tomatoes the actual optimum concentration of K might actually be larger under some condition with the optimum in this study in terms of fruit quality and yields being 300 ppm. In this last case the tomatoes were grown using a nutrient film technique (NFT) setup. However there have also been studies under other growing conditions — like <u>this one</u> on reused pumice — which shows that increasing K concentrations to 300ppm can actually have detrimental consequences. In this case tomatoes fed at 200, 290 and 340ppm of K had very similar results when using new substrate but the old substrate heavily underperformed when high K concentrations were used.

Papers published on the effect of different K concentrations in melons (here) and cucumbers (here) also point to optimal concentrations in the 200-300 ppm range and for the optimum N:K ratio to be between 1:2 and 1:3 for these plants. This is probably the reason why you will often find suggested nutritional guidelines for flowering plants — like those below taken from here — mostly suggesting K concentrations in the 250-350ppm range. However you will often find that they

directly contradict research papers, like this guideline suggesting K of 150 ppm for strawberries while we saw in a recent paper that 300ppm might be better. This is most probably due to differences in the sources used which might have used different growing systems or plant varieties which responded to other conditions better.

CROP	N	Р	K	Ca	Mg
Tomato	190	40	310	150	45
Cucumber	200	40	280	140	40
Pepper	190	45	285	130	40
Strawberry	50	25	150	65	20
Melon	200	45	285	115	30
Roses	170	45	285	120	40

Concentration in mg/l (pap)

All in all the subject of K concentration in hydroponics is no simple one. Using low K will limit your yields tremendously but increasing your K very high can also harm your plants, especially depending on the type of media you are using. In general aiming for a K concentration between 200-250 ppm is safest but in many cases increases to the 300-400ppm range can bring significant increases in plant yields. A careful study of the available literature and the actual growing conditions that the plants will be subjected to will be key in determining what the best K concentration to use will be. Alternatively carrying out adequately designed experiments under your precise growing environment will help you carry out an evidence-based decision about what K concentration to use.

Five reasons why a dedicated hydroponic testing room is a great idea

Most commercial hydroponic setups completely lack testing environments. The most common reason for this is that commercial crops are meant to produce revenue and a testing environment means dedicating space, time and money into something that might not be as productive as the rest of the production facility. Furthermore a testing room implies that you will need to create a completely independent setup and hire someone who knows how to do research in order to ensure it is both adequate and fruitful. Although many people believe this not to be worth it today I want to talk about the five most important reasons why I consider that a testing room is something incredibly useful to have as a part of your commercial growing facility and why getting one will probably pay off greatly for you going forward.



Testing product changes. Perhaps the first and most direct benefit to having a testing room is to ensure you can test

product changes. It may be the case that your supplier for some particular fertilizer product or additive has ran out and you now want to test a new product to replace it. It may also be that you want to test how a product does compared to what you generally use but you don't know if it does better or worse. Most growers are afraid of change because making facility-wide changes that won't work could have huge financial consequences. A testing room ensures you can test safely and then roll-out changes slowly without having to risk your entire crop cycle to find out.

Optimizing what you currently have. Change is very rare across commercial facilities because growers understandably want to preserve their current results, even if some better results by making some change would be possible. This constraints growers from making incremental changes that might make their crops significantly more productive. By having a testing room you can optimize the setup you already have by making adequate research into optimizing things such as environmental or nutritional factors.

Trying potentially game-changing modifications from academic research papers. There are many papers published each year on how to increase the yields of hydroponic crops. Some of these papers offer somewhat risky and controversial changes that might not transfer well across species. However if something gives you the potential to increase your yields by say, 50%, it might definitely be worth trying across a testing setup. Obviously these things are too risky to try across an entire facility but a testing room would be perfect to help you try these new and exciting modifications, potentially giving you a huge edge versus all the other people who will never try this.

Try new plant varieties. Usually growers try new plants without having a clear idea of how productive they are going to be under their growing setup. This means that you introduce a new variety with a huge question mark regarding its productivity and potentially financial benefit or cost. A

testing room provides you with a risk-free way to test how a particular plant variety will perform under the exact conditions in your facility, potentially allowing you to make far less risky decisions when it comes to making planting changes in your facility.

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Research new ideas. A final benefit you can get from a testing room is that you can research your own new ideas. With adequate experimental design even a small room with just 10 plants can be used to test some ideas to see how they affect plant growth. This means that you can develop your own inhouse growing modifications that will make it much harder for others to compete with you. For example if you developed a secret foliar additive in your growing facility it would allow you to only use this for your own crops, without the industrial secret ever being used by your competitors.

Of course there are many other advantages to testing rooms but the above are just some of the wonderful things you'll be able to do if you have a testing room and someone trained in scientific research who can help you design experiments and get the most out of it. A testing room also doesn't need to be huge and even starting out with 10 plants can be a huge step in taking your commercial growing facility to the next level.

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 $(H_2PO_4^{-} \text{ and } HPO_4^{-2})$, 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.

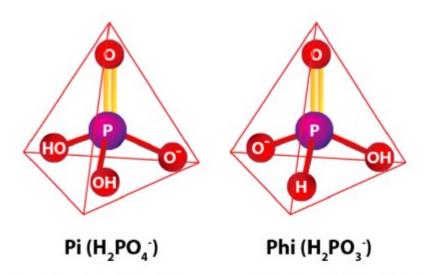


Fig. 1. Three-dimensional chemical structures of phosphate (H₂PO₄⁻; Pi) and phosphite (H₂PO₃⁻; Phi) forming tetrahedral structures.

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 1Beneficial 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 things you should know when mixing your own hydroponic liquid nutrients

Many hydroponic growers — especially large scale ones — can benefit greatly from mixing their own custom nutrients. Not only can this save money in the thousands of dollars per month but it can also give you an unprecedented degree of control when compared with store-bought nutrients. On today's post I am going to write about five important things you should know when mixing your own nutrients so you can avoid many common problems that can arise when you start preparing your own stock solutions.



More concentrated solutions are not always better. When you prepare a concentrated liquid you would usually want to go with the highest possible concentration factor so that you can prepare as much final nutrient solution as possible with as little stock solution as possible. However trying to get into higher concentration factors (1:400-1:500) can cause important issues due to the solubility of the salts used and the temperatures the stock solution will be exposed to. It can also cause high inaccuracies with variable injector setups since the dilutions will be much smaller. For starters go with a 1:100 concentration factor and only start going higher when you get more experience. If you're using injectors I would generally avoid a range higher than 1:250 unless you do more extensive calibration procedures with your injectors.

Impurities can cause important problems. Some salts can come with significant levels of impurities — sometimes mainly additives — that can cause substantial issues when preparing your nutrient solutions. Lower quality grade salts — mainly those used for soil fertilization or those that are OMRI listed and come straight from mining with no refining — can generate problems within your mixing process. These problems range from insoluble left-overs in tanks to toxic amounts of some micro elements. To ensure you get the best possible results use greenhouse grade fertilizer salts and try to avoid sources of salts that are OMRI listed. Synthetic sources that have been heavily purified are your best bet in ensuring the best possible results.

Use slightly acidic deionized water to prepare the solutions. Most water sources in Europe and the US are very heavy in carbonates an therefore inappropriate for the preparation of concentrated nutrient solutions as these ions can cause salts to precipitate when preparing concentrated solutions. To fix this issue the best thing would be to use distilled water but — since this is often not an option — the next best thing is to use reverse osmosis water and add a bit of acid (0.5mL/L of

nitric acid, other acids may cause other problems) per gallon of concentrated solution. This will ensure that everything gets dissolved and will eliminate the carbonates that can be naturally present within the water. Of course never, ever use tap or well water to prepare concentrated hydroponic solutions.

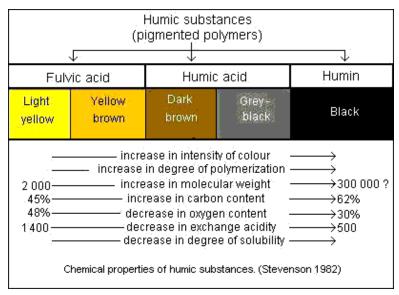
Salts take up volume, take that into account. A very common mistake when preparing solutions is to just add the salts to the final volume of desired stock solution to prepare. This is a mistake since the salts also take up volume. If you want to prepare 1 liter of concentrated solution and you need to add say, 100 g of potassium nitrate, adding 100g of potassium nitrate to 1L of water would generate a solution with a final volume greater than 1L. To avoid this problem always add the salts to half the volume of water and, after the salts have dissolved, complete to the final volume of desired solution.

Add salts from the smallest to the largest quantities. When you prepare hydroponic solutions it is often better — especially when you're starting — to add salts from the smallest to the highest amounts needed. If you make a mistake at some point then you will minimize the amount of mass of salts that has been wasted due to this fact. If you make a mistake adding a micro nutrient you will only lose a small amount of the other micro nutrients instead of losing a huge amounts of macro nutrients due your order of addition. It is also true that the substances that are added in largest quantities are commonly nitrates and these salts have endothermic dissolutions — meaning they cool solutions upon addition — so it is better to add them last so that they can benefit a bit from the heat generated by the dissolution of the other salts.

The above is not an exhaustive list of pointers but it should save you from some important trouble when preparing your own initial nutrient solutions. Although some of these points may seem obvious to those that have experience preparing their own solutions they may prove invaluable to those who are just starting their journey in concentrated nutrient preparation.

Humic acids in hydroponics: What is their effect?

Plants and microorganisms affect the substrates in which they grow in many ways. If you start growing plants in an inert substrate — with nutrient applications of course — you will notice that the substrate's chemical composition will start to change with time and it will start to get enriched in carbon containing substances. As plants and microorganisms grow, thrive and die, some of the chemicals that made up their cells end up enriching the substrate they grow on. This process — whereby organic materials from living organisms become part of a substrate — is what generates the soils around us. One of the most prevalent class of components in this organic material, is what we call humic acids.



Humic substance chemical properties.

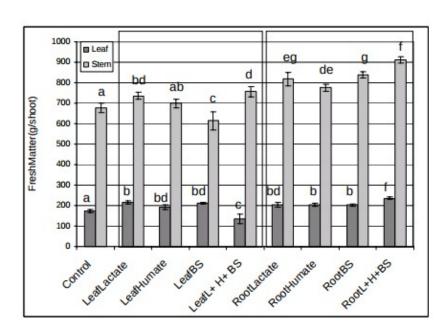
Humic acid is not a single substance but a wide range of substances that are created as a product of plant and microorganism decomposition. This is why you often hear people talk about "humic acids" instead of simply "humic acid". They are called "acids" because the humic substances contain molecules that have groups that resemble those found in phenol and vinegar. They are also differentiated from fulvic acids in the fact that they are only soluble at basic pH values while fulvic acids are generally small enough molecules to be soluble across most of the pH spectrum. Since humic acids are a very important component of enriched soils and can be used in soiless culture, people have started using them as supplements in soiless and pure hydroponic culture.

When talking about the effects of humic acids it is worth mentioning that since we're talking about a group of molecules — not a single substance — effects are generally dependent on the source of the humic acid used. For example you can find a study on tomatoes here where two different sources of humic acids — from peat and leonardite — were used to grow tomatoes. The study shows a clear difference between both with the first only stimulating root growth while the second stimulated both roots and shoots. However in both cases there was an increased iron availability to plants, although the mechanism for this was not established.



Tomato plants inoculated with root rot at different humic acid application rates

In plants like gerberas humic acids applied at 1000 ppm can offer increases in harvested flowers of up to 52% (see here), somewhat positive effects can also be seen in tomatoes across the literature with most studies showing increases in yields and mineral contents (see here), reports of positive effects on gladiolus have also been published (here). Since the 1990s there has been a somewhat established understanding of some general beneficial effects for humic acid applications, it is well established that they can prevent and eliminate micro nutrient deficiencies due to their abilities to increase their availability(see here). The literature is also consistent in that the largest effects are often seen on root growth rather than on shoot growth or mass. There are however some types of humic acids that have showed higher increases of shoot mass, for example in <u>an article</u> studying substances derived from municipal waste on barley this was the observed effect. For some plants however - despite these beneficial effects — increases in yields in hydroponic culture are not evident (see here and here). A look at the effect of a humic acid source on several different plant species can be found here.



Effect of humic acid, bacteria and lactate applications on tomato plants.

It is worth noting that humic acid applications are also not limited to the root zone. Since humic acids can enhance the absorption of some nutrients they can also be applied in foliar sprays. Experiments on strawberries (here) showed that an application of 1.5-3ppm of humic acids led to an increase in the quantitative and qualitative properties of the fruits. Combinations of humic acids with other biostimulants are also common. For example a combinations of lactate, humate and beneficial bacteria was tested on tomatoes (here) but the experiments showed that the effect could be stimulating or inhibiting depending on the particular conditions, even though most combinations were beneficial.

With the high variability between humic substance origins, application rates and effects it is very hard to say whether humic acid applications will definitely help your crops in terms of yields. For almost all humic acid sources it probably warranted that micronutrient absorption will somewhat augmented due to their ability to chelate these nutrients, but only if the nutrients are not efficiently chelated already. This sole ability might lead to crop improvements if deficiencies are present but improvements in yields will strongly depend on humic acid substance origin and particular properties. However humic acids do seem to lead to general product quality improvements and since negative effects are rare there seems to be no harm in carrying out field tests to determine if their use is worth it for your particular crop.