Sugars in hydroponic nutrient solutions

Carbohydrates are an integral part of plants. They produce them from carbon dioxide, requiring no additional external carbon inputs for the process. However, since plants can absorb molecules through their leaves and roots, it is perhaps natural to wonder whether they could also get carbohydrates through the roots and avoid some of the stress they go through in order to produce these molecules from scratch. If plants can uptake sugar and we feed them sugars then will we get fruits with more sugars and bigger plants? It's an interesting question that I will try to answer within this post, looking at the potential use of simple sugars within hydroponic nutrient solutions.

Simple table sucrose

Although the above idea sounds straightforward, it hardly has any interest in the scientific literature or the commercial hydroponic industry. You will find no significant number of research papers studying the use of sugars – simple or complex – in hydroponic nutrient solutions and very few studies looking at sugar uptake and the interactions of *in-vitro* plant tissue with simple sugars. *This lack of interest and use is no accident, it comes from an already established understanding*

of plant physiology and the realization that it is not cost effective, useful or needed to add sugars to nutrient solutions.

Let us start with what we know about the subject. We know that plants exude very significant amount of sugars through their root systems and we also know that they can re-uptake some of these sugars through their roots (see here). From this paper it seems that maize plants could uptake up to 10% of the sugars they exude back into their root systems, which implies that some exogenous sugar application could find its way into plant roots. Even worse, transporting this sugar up to the shoots is extremely inefficient, with only 0.6% of the sugar making it up the plant. This tells us that most of the sugar is wasted in terms of plant usage, a large majority never makes it into the plant and the little amount that makes it actually never goes up the plant. *Plants are simply not built to transport sugars in this manner, they evolved to transport sugars down to roots and to fruits*.

But what about the roots? Given that the plant tissue that would be in direct contact with the sugar is the roots, it is logical to think about positive effects affecting them primarily. We have some studies about the influence of sugar solutions in seedlings (like this one) which does show that sugars can stimulate the growth of new root tissue in very small plants. However in large plants most of the sugar content in the roots will come from transport from the higher parts of the plant and the local sugar concentration will be low. Seedlings can likely benefit from sugars in the roots because leaves are producing very little at this time but larger plants are unlikely to benefit from this effect.

There is however one effect that sugars have that is very clear, they feed the rhizosphere around the plant's roots. Although plants try to care about this themselves – by exuding an important amount of sugars and organic acids – an exogenous sugar addition would most likely boost the amount of microbes

around plant roots (both good and bad ones). The profile of sugars and acids exuded by plants is most likely tuned by evolution to match the microbes that are most beneficial to it and an unintended and negative effect of sugars is to boost all microbe populations at the same time, regardless of whether they are good or bad for the plant. This also increases oxygen demand around roots – because aerobic microbes will want to oxidize these sugars – reducing the amount of oxygen available to plant roots. For this reason, any application of a sugar to a nutrient solution requires the inoculation of the desired microbes beforehand, to ensure no bad actors take hold. It also requires the use of a media with very high aeration, to prevent problems caused by oxygen deprivation.

Sadly there aren't any peer reviewed papers – at least that I could find – investigating the effect of exogenous sugars on the yields of any plant specie in a hydroponic environment. Given our understanding of plant physiology, any positive effects related with anecdotal use of sugars are most likely related with positive effects in the rhizosphere that are linked with improved production of substances that elicit plant growth in the root zone by favorable microbes. This is mainly because it is already well established that transport of sugars within plants from the roots to the shoots is incredibly inefficient, so any contribution of the roots to sugar uptake will be completely dwarfed by the actual production of sugars from carbon dioxide in the upper parts of the plant. It is not surprising that no one seems to want to do a peer reviewed study of a phenomenon whose outcome is already largely predictable from the accepted scientific literature.

If you're interested in the use of sugars in hydroponics, it is probably more fruitful to focus on microbe inoculations instead. Sugars themselves are bound to provide no benefit if they are not coupled with a proper microbe population and,

even then, you might actually have all the benefits without any sugar applications as the microbes can be selected and fed by plant root exudates themselves in mature plants although sugars might provide some benefits in jump starting these populations, particularly in younger plants. Also, bear in mind that there is also a very high risk of stimulating bad microbes with the use of sugars, especially if oxygenation is not very high.

Maximizing essential oil yields: A look into nutrient concentrations

Essential oils are the main reason why several plant species are currently cultivated. These oils have a wide variety of uses either in the food industry or as precursors to more complex products in the chemical industry. Modifying nutrient solutions to maximize oil yields in hydroponic setups is therefore an important task. However, there are sadly no clear guidelines about how this can be achieved. In today’s post I wanted to create a small literature review of different research papers that have been published around the modification of nutrient solutions to maximize essential oil production and see if we can draw some conclusions that should apply to plants that produce them.

The variety of plants that produce essential oils is nothing but amazing. From plants where mainly the leaves are harvested – such as mint and basil – to plants where the flowers are used – such as roses – to plants where the seeds are used, like coriander. The wide variety of oil sources and plant species implies that the universe of potential research is immense, with every potential nutrient modification in every plant giving a potentially different optimal measurement. However, plants share some important characteristics – like photosynthesis and root absorption of nutrients – plus essential oils within different plants can share components produced using similar chemical pathways. For this reason, a look into the research universe of nutrient solution optimization for essential oil production is likely to serve as a base to guide us in the optimization of a solution for a particular plant.

Plant	Optimal (ppm)	Link to reference
Mint	195-225 N , 178-218 K	https://www.actahort.org/books/853/853_18.htm
Sweet Basil	180 Ca	https://www.cabdirect.org/cabdirect/abstract/20013048426
Costmary	200 N, 200 K	https://pubag.nal.usda.gov/catalog/732179
Mint	<= 276 K	http://www.scielo.br/scielo.php?pid=s0103-84782007000400006&script=sci_arttext
Chrysanthemum	159 Ca	https://pdfs.semanticscholar.org/13ea/999605458e65d9023dadbabca48464a5fa70.pdf
Chrysanthemum	43 N (NH4)	https://tinyurl.com/vqupwvf
Lavender	300 K	https://scielo.conicyt.cl/scielo.php?pid=S0718-95162017005000023&script=sci_arttext&tlng=en
Rose Geranium	207 K	http://ir.cut.ac.za/handle/11462/189

Rose Geranium	110 S, >= 68 P	https://www.tandfonline.com/doi/full/10.1080/02571862.2012.744108
Spearmint	200 N	https://www.sciencedirect.com/science/article/abs/pii/S2214786117300633
Lavender	200 N, 50 P	https://www.sciencedirect.com/science/article/abs/pii/S0926669015306567
Mint	414 K	https://sistemas.uft.edu.br/periodicos/index.php/JBB/article/view/601
Spearmint	50-70 P	https://www.sciencedirect.com/science/article/pii/S0308814618317862
Marjoram	>= 36 Mg	https://www.actahort.org/books/548/548_57.htm
Salvia	150 N	https://pubs.acs.org/doi/abs/10.1021/jf030308k
Dill	300 N	https://www.actahort.org/books/936/936_22.htm

Summary of different papers addressing essential oil yield optimization in hydroponic setups by varying one or several nutrient concentration values.

In the table above I summarize the research I found concerning the optimization of some mineral nutrient in the hydroponic production of a plant, specifically to maximize the essential oil yield. All of these studies optimized the nutrient within a given range and a >= or <= sign is used whenever the optimal value found is at the top or bottom of the range respectively. When more than one nutrient was optimized in the paper, I give you the values for both nutrients so that you can glimpse the optimal. Whenever the researchers suggest an optimal range instead of a value within their research this is also included as a range. I tried to find papers representing all macro nutrients but studies optimizing some elements were hard to find (Mg for example). Although I tried to include as many species as possible some species are just more commonly studied, as they are commercially more relevant (like mint and basil).

From these research results we can immediately see some clear trends. From all the studies there is no result where optimal total nitrogen concentration is below 150 ppm and 3 out of the 4 studies I found, agree that the optimal N concentration is at 200 ppm. In the case of K all studies agree that K should be at least 200 ppm, but I did find a study on mint that got a value of 414 ppm, far larger than the value found in other studies for the same specie. This is not an uncommon discrepancy in hydroponics – optimal yields being mixed in a wide range above 200 ppm of K – which can be caused by other

issues that can affect K absorption, such as the concentration of other important cations (like Ca and Mg) in the studies.

I was only able to find two studies that focused on Ca and both agree about optimal values between 150 and 180 ppm, although they address two completely different plant species (basil and chrysanthemum). In the case of Mg I found only one study and its conclusion was mainly that you want to have more than 36 ppm of Mg in solution. This is not surprising as Mg is rarely a growth limiting element in hydroponics and usually growth will not be limited to it unless its supply is very low compared to the supply of other nutrients (which is very rarely the case).

In the case of P, it’s not surprising that most papers that addressed this nutrient studied plants where the essential oils are mainly in the flowers (rose and lavender), as phosphorous is a nutrient commonly associated with flowering. In the case of rose the best value in the study was sadly the upper limit and in the case of lavender the optimal value reached was 50 ppm. In this case we can therefore probably only say that both studies share having an optimal result of >= 50 ppm but it’s hard to provide an upper bound for this. A study addressing P in spearmint also finds optimal P to be within exactly this range at 50-70 ppm.

Element	ppm
N	200
P	60
K	200
Ca	160
Mg	45

A base “guess’ formulation for a plant producing essential oils

With these results in mind, we can sketch a base solution for a plant where essential oil production is being targeted.. An

obvious guess would be to start with a solution with the concentration profile showed above. In this case we target N and K at 200 with an N:K ratio of 1 and we keep Ca at 160, making the K:Ca 1.25 (which is surprisingly close to the optimal value discussed in my Ca post). We leave P at 60 – the middle of the 50-70 range – and we keep Mg at 45, which is > 38 and is a value commonly used in regular hydroponic solutions. **The above will certainly not be the best solution for any single plant *a priori*, but it might provide a good base to start optimizing from if the objective is essential oil production.**

The media exchange solution test: A better measurement of media effects in hydroponics

In the traditional hydroponic paradigm we want media to be as chemically inert as possible. The ideal media in this view would absorb no nutrients, give off no nutrients and would not decompose or react with the nutrient solution in any way. However none of the commonly available media sources comply with these properties, reason why we must be vigilant and properly adjust the media we use to fit the needs of our hydroponic setup. In this article I am going to talk about the idea of using a direct comparison test of the nutrient solution against the media, to understand the effect the media will have when exposed to the target nutrients and how this can help us adjust our solutions to better play with the selected growing medium.

Different types of growing media

First, let us understand how the media interacts with a hydroponic solution. The media can do all of the following things:

- **Dissolve into the solution** (this is what happens if your media is something like sand or limestone). In this case the media is chemically reacting with the nutrient solution, therefore media is being irreversibly lost in the process. This can happen very fast, with something like limestone, or very slowly, with something like sand.
- **React and take something away from the solution**. In this case the media can use ions within the solution to perform reactions that create new substances that are insoluble. For example if you have media containing large amounts of rock phosphate this phosphate can cause the precipitation of heavy metal phosphates.
- **Release ions in exchangeable locations into the media.** This is different than dissolving because the media is not getting destroyed in the process but it is emptying "storage sites" that contain some ions that prefer the solution instead of these sites. This process is fundamentally reversible and – under the proper conditions – these sites could be replenished with the

same or different ions.

- **Take ions into exchangeable locations in the media.** This is the opposite of the process above. In this case the media will receive some ions into “storage sites” because these ions prefer the media to the hydroponic solution. The solution will therefore be depleted of these ions because they are being stored within the media.

Of most interest to us are the third and fourth points above, this is generally understood as the “exchange capacity” of the media. This determines how many and which nutrients the media can store. Different media can have storage sites with different affinities and in hydroponic setups we generally want to aim for the minimum energy state of these storage sites as they relate to our nutrient solution. Media that is already in equilibrium with the nutrient solution will tend not to change it while media that is far away from equilibrium with the solution will change it strongly towards the equilibrium point.

Think about coco coir, a commonly used media in hydroponics that can have a wide variety of different ion exchange capacity values and a lot of different ions initially in its “storage sites” due to the differences in sourcing materials and treatments done by different companies. Coco coir initially contains high amounts of potassium and sodium ions, but some companies treat it with Ca nitrate, which changes all these “storage sites” to contain Ca instead. These two sources of coco would interact very differently with our nutrient solution. In the first case the coir would exchange a lot of its potassium for Ca and Mg ions in solution – because these ions have higher affinity for the “storage sites” – while in the second case a little Ca would be exchanged for other ions (because all ions are in equilibrium with all the storage sites). The changes to the solution are very different and totally different approaches in nutrient composition changes

are required.

Traditional soil tests could provide some answer to us, they would definitely show the ions that could be exchanged to be different in both cases. But they tell us little about the equilibrium position of the media against our target nutrient solution. To make things more realistic we can actually do a test where we pass our actual nutrient solution through a column of media that is exactly what we're going to run it through in real life (with no plants of course). We then collect the input and output solution and run lab analysis of both of these solutions. **We can then compare the results and see how much the media is actually changing the composition of our input solution and we can then make some decision to adjust.** Such a test would proceed as follows:

1. Prepare the strongest final solution that will be used in the growing process. (for example the solution that is used at the peak of fruit generation in a tomato crop)
2. Take a sample of this starting solution to send for chemical analysis.
3. Pack a burette with a column of media as high as the containers the plants will be in.
4. Fill the burette with the nutrient solution.
5. Run as much solution as required to collect a sample of equal volume to the first one.
6. Send both samples for analysis.

The difference in nutrients between both solution will show us what we should initially be doing to maintain a consistent composition of the nutrient solution, given the interaction with the media. If the interaction is too strong it can also tell us that we shouldn't be using this media without previously treating it to ensure the imbalances do not happen. For example media like biochar can have an extremely high affinity for metal chelates and nitrogen compounds, if we ran our solution through the media and it turns out that it soaked

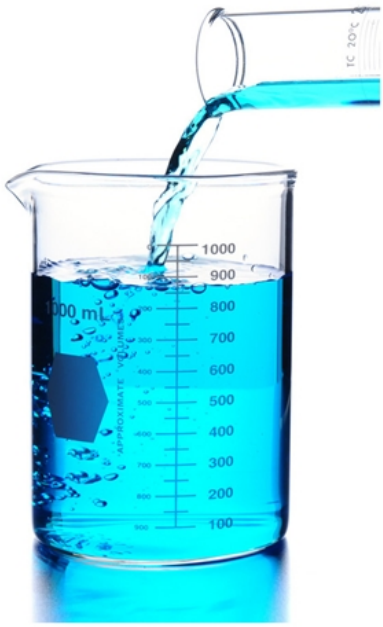
up almost all of our iron and ammonium, we wouldn’t want to just add more nitrate and heavy metals but we would like to pretreat the media with a concentrated solution and then repeat the test to ensure that the media is at a level of activity that we can correct for.

A given media source that is acceptable should not strongly affect the nutrient solution. Any media that does this in the media exchange test requires correction so that the ability to take elements from the nutrient solution is reduced. The test will tell you exactly what the media is finding most appetizing and the treatment options will then be substantially easier to plan. A coco coir that shows it soaks up almost all the Ca will need to be treated with a Ca nitrate solution and a biochar that absorbs a lot of ammonium will need to be treated with an ammonium sulfate solution. These are some cheap pretreatments that will save a lot of heartache within a hydroponic setup and will make the ongoing growing process substantially easier to manage.

This is one of the simplest and cheapest tests that can be done to address media effects. However it is by no means comprehensive in that it does not show us other important media properties that might be crucial for selection. It is important to consider that this test gives us only a glimpse of the chemical properties and the interactions with the actual nutrient solution we intend to use. Other media specific analysis and more complicated media run-off tests can be necessary to address the full extent of the interactions through an entire crop cycle.

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.