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.**

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.



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).

Evidence from experiments on tomatoes (link here 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 this one 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.

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.

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.

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.

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.

Maximizing yields per area in hydroponics

Since the 1940's hydroponics – which I use to talk about a broad variety of soilless growing methods – have promised to deliver better plant yields than soil culture with less water usage and higher fertilizer efficiency. However there are many different types of soilless cultures that vary in their initial cost, media used, irrigation method used and potential for yield. Today I want to talk about the decisions that need to be made if you want to maximize yields in a hydroponic crop and the compromises that you may have to make in order to get there.

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There are mainly two ways in which yields can be increased in crops. The first is to increase the amount of production you can achieve per plant and the second is to increase the amount of plants you can have per area. Maximizing crop production requires using methods that allow you to reach the best compromise between these two, maximize the product of plants per area with production per plant. This often means not having the largest amount of plants you could possibly grow per square meter and not having the largest possible yields you could have per plant.

Assuming that plants are getting adequate lighting and carbon dioxide there are two things that can be done to maximize the amount of yield per plant. The first is to ensure that plants can get optimum contact with nutrient solution as often as possible. This means that nutrient solution should always be saturated with oxygen and that irrigation should happen as often as possible. This ideally means that the media should not allow for any waterlogging but should allow the solution to flow freely and constantly. The second is that the nutrient solution should contain adequate amounts of all nutrients – all within the plant's sufficiency ranges – with adequate temperature, pH and EC values. The optimum nutrient ratios in solution depend on the plant being grown and they can play a substantial role in getting better yields per plant, especially in flowering crops. Here are some scientific articles with some experiments about some of the above (1, 2, 3, 4, 5, 6).

A typical problem when maximizing yields per plant is that this immediately means larger energy expenditure. It often means close to constant irrigation systems with highly

efficient oxygen pumps. It also means potentially more expensive media – such as expanded clays or rockwool – with closed systems where solutions need to be closely monitored. Systems of this sort are more vulnerable to power outages and they are much less forgiving with grower mistakes. Plants are much more dependent on the ideal conditions being created around them and deviations from these conditions can eliminate any potential advantages that were obtained when going for this system class.

Our next area of yield maximization is to increase the number of plants per area. To do this we basically need to increase two things: light and ventilation. The main limiting factor in having more plants is the light that they can receive so either changing to systems where light can be better distributed – such as growing towers – or using more lights can alleviate this problem. Some growers have even used high power LED strips between plants to fix this issue. Since plants also absorb carbon dioxide around their leaves we also need to ensure we have stronger ventilation to ensure none of our plants are getting starved. Increasing plant density also increases the propensity of our plants to catch and transmit diseases so environmental manipulations like lower humidity are often coupled with increases in density to decrease these risks. See these articles for more on yields, light and density (1, 2, 3, 4).

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Increasing plants per area automatically decreases yields after one point but it is often the case that you can get larger final yields per area by compromising some yield per plant in the process. Even if plants yield 10% less this might be worth it if you can include 2 more plants for every 10

within your hydroponic crop. The key to maximizing yields per area is to find how far you can push this before getting substantial issues that may dramatically decrease plant yields.

It is worth noting that steps taken to maximize yields are also often steps taken in making the crop more susceptible to problems. While lower yielding setups, like for example run to waste setups with sparse plant density, are often easy to manage and very forgiving, more technical setups like closed loop constant irrigation systems at high plant densities can be much better yielding but much more prone to problems, requiring much closer monitoring and attention. This is why many growers might get better yields with setups with lower yielding potential, because their mistakes are punished much less harshly under these conditions.