How to get more phosphorus in organic hydroponics

It is difficult to supply plants with readily available phosphorus because of the insolubility of many phosphorus compounds (2). Whenever orthophosphoric acid species are present in a solution, all the heavy metals, calcium, and magnesium form progressively insoluble phosphate salts as the pH increases (3). At high pH, all of the phosphate is expected to be precipitated as long as there are excess cations to form these insoluble salts. In this post, we are going to talk about how this problem exists mainly in organic hydroponics and how we can solve it by efficiently using organic sources of phosphorus.

Seabird guano, one of the few organic, high P, soluble sources for organic hydroponics

Phophorus in traditional hydroponics

In hydroponic systems that are not organic, soluble phosphorus salts are used to provide the phosphorus necessary for plant growth. These salts are all synthetic and are therefore not allowed for use in organic crops. They are mainly mono potassium phosphate (MKP) and mono ammonium phosphate (MAP). At the concentrations generally used in hydroponics – 25-100 ppm of P – at a pH of 5.8-6.2 and in the presence of chelated heavy metals, the phosphorus all remains soluble and there are rarely problems with phosphorus availability that are directly related to the P concentration in solution. However, when trying to move to an organic hydroponic setup where we want to avoid the use of all these synthetic salts, we run into big problems with P availability.

Organic soluble phosphorus fertilizers

The first problem we find is that there are no organic sources that are equivalent to MAP or MKP. However, there are thankfully some highly soluble organic sources that contain significant amounts of P. Some guano sources are particularly high in P, especially Seabird Guano (0-11-0), while some vegetable sources like corn steep liquor (CSL) (7-8-6) can also have high phosphorus (1, 9).

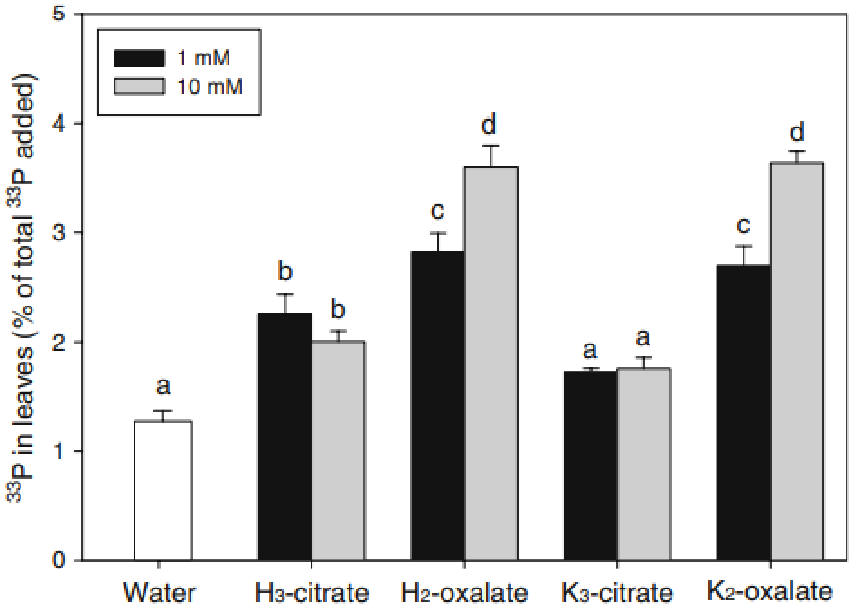
However, these sources do not only contribute phosphorus but will also contribute a variety of different substances that need to be taken into account when considering them for use. In the case of CSL, very high lactate and organic nitrogen levels imply that you will need to prepare an appropriate compost tea to use this in a nutrient solution. I wrote a blog post about a paper that describes how to make such a preparation.

In the case of seabird guano, a lot of calcium is also provided (20%) so we also need to take this into account in our formulations. *Using 3g/gal of seabird guano will provide you with a solution that contains 38ppm of P and 158ppm of Ca*, although not in exactly readily available form – as MKP would provide – it will become available much easier than insoluble phosphate amendments. Seabird guano applications should be enough to completely cover both the P and Ca requirements of most flowering plants. The seabird guano also includes a lot of microbial activity, which will reduce the oxygenation of the media when it is applied, reason why you need to be careful with the aeration properties of your media (as I mentioned in this post).

These organic sources of P might also contain significant amounts of heavy metals. Seabird guano can be notable for having significant levels of cadmium (4, 5) so make sure you have a heavy metal test of the soluble P source you intend to use to ensure you're not adding significant amounts of heavy metals to your crops.

Insoluble organic phosphorus amendments

Besides these soluble organic phosphorus sources, we also have the possibility to use mineral amendments that can be directly incorporated into the media from the start. These sources offer us some additional advantages relative to the pH and nutrient stability through time, which are not offered by using the soluble solutions. The most common amendments available in this area are rock phosphates and bone meal. Not all rock phosphates and bone meal sources are created the same though, rock phosphates mined across the world can differ in their carbonate content, which can greatly affect their solubility. *These amendments are generally used at around 60-120mL per gallon of soil.*



P uptake for different concentrations of citrate or oxalate.

Plants, however, will respond to low P in their root zone by releasing organic anions that can chelate metals and slowly dissolve these phosphates (6). Tests by adding organic acids directly do show that not all acids are the same and some are much more effective than others. In this article (7), the authors showed that oxalic acid was more effective than citric acid in making P available from a rock phosphate source. Malic acid, a very important organic acid for plants (8), can also be used for this purpose and is preferable to oxalic acid. This is because oxalic acid is not only toxic to humans but can also strongly precipitate metals like iron, which are also needed by plants.

From the literature, we can conclude that adding these acids ourselves in concentrations of around 1mM, can be a good way to help solubilize P contained in these rock phosphate amendments. Watering with a solution of citric or malic acid at 150mg/L (567mg/gal) can help free these rock phosphate amendments and contribute to plant absorption of both the phosphorus and the calcium that is bound with it. Alternatively, we can also use fulvic acid at 40mg/L to achieve a similar effect (10).

Conclusion

While there are no easy replacements for phosphorus in organic hydroponics, there are some satisfactory solutions. Soluble phosphorous sources like CSL and seabird guano can be used to provide large amounts of soluble P when required, while solid amendments like rock phosphate and bone meal can provide a sustained release of these nutrients with time, also increasing the pH stability of the media. While using only soluble sources can be the easiest initial transition from a purely hydroponic crop, it will also be harder to manage due to the effects on media pH that such applications might have. A combination of both approaches – soluble applications and amendments – can often be the most successful when implementing an organic hydroponic approach.

Organic nitrogen in hydroponics, the proven way

Nitrogen is a critical nutrient for plants. In hydroponics, we can choose to provide it in three ways, as nitrate, as ammonium or as organic nitrogen. This last choice is the most complex one. It contains all possible nitrogen-containing organic molecules produced by organisms, such as proteins and nucleic acids. Since nitrate and ammonium are simple molecules, we know how plants react to them, but given that organic nitrogen can be more complicated, its interactions and effects on plants can be substantially harder to understand. In this post, we will take an evidence-based look at organic nitrogen, how it interacts in a hydroponic crop and how there is a proven way to use organic nitrogen to obtain great results in our hydroponic setups.

An organic nitrogen source, product of corn fermentation, rich in protein and humic acids

Nitrogen uptake by plants

The main issue with organic nitrogen is its complexity. Plants will mainly uptake nitrogen as nitrate (NO_3^-) and will also readily uptake nitrogen as ammonium (NH_4^+) to supplement some of their nitrogen intake. However, organic nitrogen is made up of larger, more complex molecules, reason why its uptake is more complicated. Various studies have looked into whether plants can actually uptake organic nitrogen directly at all (1, 2). They have found that while some uptake is possible, it is unlikely to be the main contributor to a plant's nitrogen uptake. While plants might be able to uptake this organic nitrogen to some extent, especially if it is comprised of smaller molecules (3, 6), it is unlikely that this nitrogen will be able to replace the main absorption pathway for nitrogen in plants, which is inorganic nitrate.

Effects of organic nitrogen in hydroponics

Many researchers have tried to figure out what the effect of organic nitrogen is in hydroponics. This study (4), looked at the effect of various organic nitrogen sources in the cultivation of lettuce. The study tried to measure how these fertilizers compared against a complete Hoagland solution. The results show that the organic nitrogen sources were unable to successfully compete with the standard mineral nutrition. The best result was obtained with blood meal, with less than half of the yield obtained from the Hoagland solution. It is clear that this study is not fair, as using organic nitrogen sources as the sole source of nutrition means more deficiencies than simply nitrogen might be present, but it does highlight some of the challenges of using organic nitrogen in hydroponics.

Another study (5), performed a more direct comparison of various different nitrogen sources, changing only the nitrogen source between nitrate, ammonium, and organic nitrogen in the cultivation of tomatoes. Organic nitrogen performed the worst across most measurements in the study. This showed that organic nitrogen is, by itself, not a suitable form of nitrogen for plant absorption and is unable to replace the nutrition provided by a synthetic inorganic nitrate source. This is especially the case when the organic nitrogen comes from more complex sources.

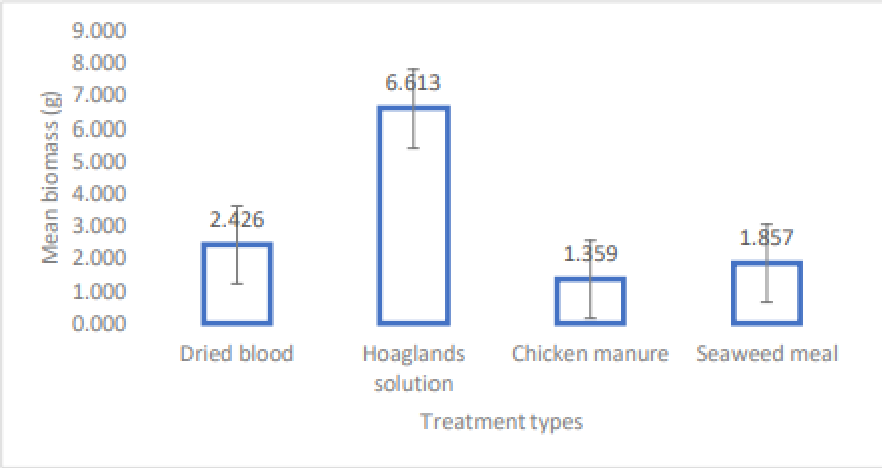


Figure 10: Compares the mean values for dried lettuce biomass of the four different treatment types.

Taken from this thesis.

How to solve these issues

As we've seen, the main problem with organic nitrogen is that plants cannot uptake it efficiently. However, the nitrogen cycle provides us with mechanisms to convert organic nitrogen into mineral nitrate which plants can readily metabolize. The best way to achieve this is to prepare compost teas using the organic nitrogen source to create a nutrient solution that is better suited for plants. The use of nitrifying organisms provides the best path to do this. These organisms are present in a variety of potting soils and composts, but can also be bought and used directly.

This study (7) showed how using goat manure coupled with nitrifying bacteria was a viable path to generate a nutrient solution suitable for plant growth. Another study (8), also using manure, confirms that viable nutrient solutions can be created and used to grow crops successfully when compared to hydroponic controls. Manure, as an animal waste product, contains a lot of the macro and micronutrients necessary for plant growth, providing an ideal feedstock for the creation of a full replacement for a nutrient solution.

Another interesting study (9) uses vegetable sources in order to study the creation of such solutions. I recently used this study to create a detailed post about how to create a nitrate-rich compost tea for use in hydroponics starting from corn steep liquor and bark compost as inputs.

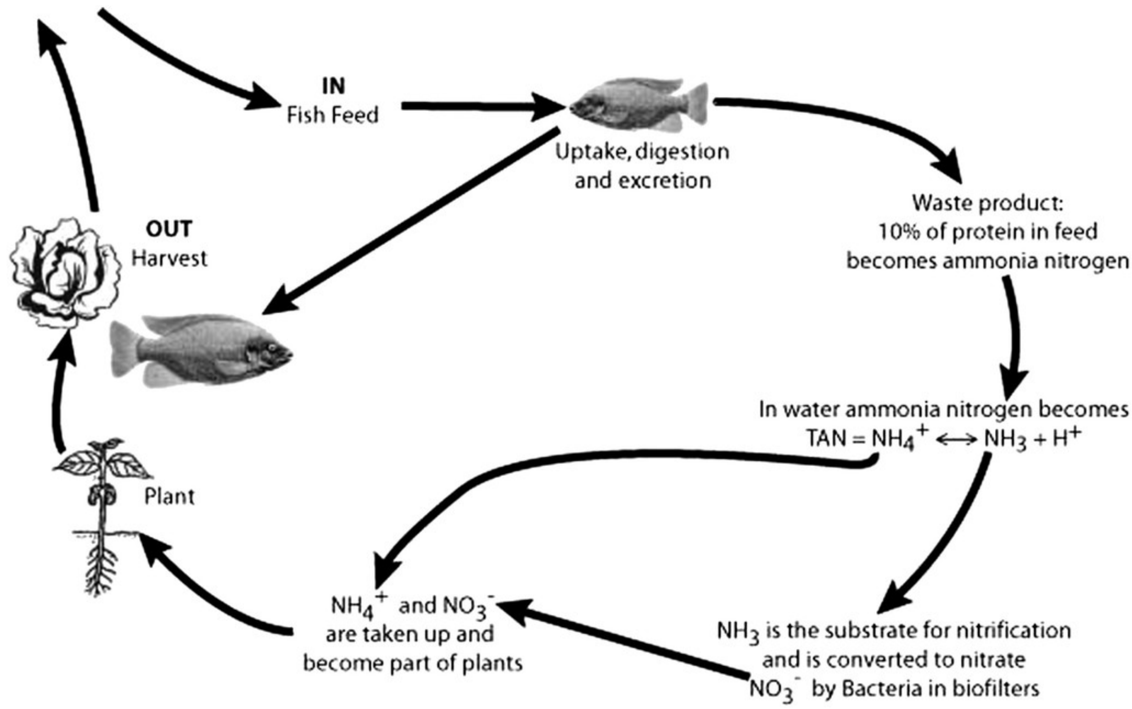
In conclusion

Organic nitrogen sources, by themselves, are not suitable as the main source of nitrogen for plant growth. This is especially true of very complex nitrogen sources, such as those contained in blood meal, corn steep liquor and fish emulsions. However, we can take advantage of nitrifying bacteria and use these inputs to create nitrate-rich solutions that can be used to effectively grow plants. *This is a proven solution that has been tried and tested in multiple studies and in nature for hundreds of thousands of years*. Instead of attempting to use organic nitrogen sources either directly in the hydroponic solution or as media amendments, create compost teas with them that contain readily available mineral nitrate instead.

Do you use organic nitrogen in hydroponics? What is your experience?

Aquaponics vs hydroponics, which is best and why?

In hydroponic culture, plants are grown with the help of a nutrient solution that contains all the substances required for plant growth. In these systems, the nutrient solution is prepared using externally sourced chemicals, which can be of a synthetic or natural origin. On the other hand, in aquaponics, a plant growing system is coupled with an aquaculture system – a system that raises fish – so that the plants feed on the waste coming from the fish. In theory, aquaponics offers the benefits of a simplified, closed system with an additional upside – the ability to produce fish – while a hydroponic system requires a lot of additional and more complicated inputs. Through this post, we will use the current peer-reviewed literature to take a deep look into aquaponics vs hydroponics, what are the advantages and disadvantages and why one might be better than the other. A lot of the information below has been taken from this 2019 review on aquaponics (9).



Basic process diagram of an aquaponic setup (from here)

Complexity

An aquaponic system might seem simpler than a hydroponic system. After all, it is all about feeding fish regular fish food and then feeding the waste products to plants. However, it is actually not that simple, since there are substantial differences between the waste products of fish and the nutritional needs of plants. One of the most critical ones is nitrogen.

This element is excreted by fish in its ammoniacal form but plants require nitrogen in its nitrate form. This means that you need to have a biofilter system containing bacteria that can turn one into the other. Furthermore, the chemical conditions ideal for nitrification are basic, while plants prefer solutions that are slightly acidic. This mismatch in the optimal conditions of one system compared to the other makes the management of an aquaponic system substantially more complicated than the management of a traditional hydroponic system (1).

Furthermore, plant macronutrients like Potassium and Calcium and micronutrients like Iron are often present at low levels in aquaponic solutions. Plants that have higher demands for these elements, such as large flowering plants or some herbs, might have important deficiencies and issues when grown in an aquaponic system (2, 3). This means that supplementation is often required in order to achieve success with these crops. Achieving ideal supplementation rates often requires chemical analysis in order to properly gauge the amounts of these elements that are required.

Additionally, aquaponic systems require additional area for fish and a lot of additional labor to manage the fish, the biofilters, and other sections of the facility that would not exist under a purely hydroponic paradigm. This article (16), better describes some of the economic and practical tradeoffs in terms of complexity when going from a hydroponic to an aquaponic facility.

Yield and quality

Given the above, it could be easy to think that yields and quality of products coming from aquaponics would be worse. However, the evidence points to the contrary. Multiple studies looking at aquaponics vs hydroponics quality and yields have shown that aquaponics products can be equivalent or often superior to those produced in hydroponic environments (4, 5, 6, 7, 8). A variety of biological and chemical factors present in the aquaponic solution could offer bio-stimulating effects that are not found in traditional hydroponic solutions. For a detailed meta-analysis gathering data from a lot of different articles on aquaponics vs hydroponics see here (14).

The best results are often found with decoupled aquaponic systems. In these systems, the aquaponic system is treated as separate aquaculture and hydroponic systems. The nutrient solution is stored in a tank that is used by the hydroponic facility as its main feedstock to make nutrient solution. Its chemistry is then adjusted before it is fed to the hydroponic system.

An aquaponic setup growing leafy greens

Growing Systems

Traditionally, Nutrient Film Technique (NFT) systems have been preferred in commercial hydroponic culture due to their high yield and effectiveness. However, aquaponic systems do better with setups that can handle large levels of particulates, due to their presence in the aquaponic nutrient solution. For this reason, deep water culture (DWC) is the preferred method for growing in commercial hydroponic systems. This is also because dark leafy vegetables are the most commonly grown products in aquaponic setups and DWC setups are particularly well suited to grow this type of plants.

Sustainability

Aquaponic systems are, on average, more sustainable than hydroponic systems in terms of fertilizer usage. When comparing Nitrogen and Phosphorus usage between a hydroponic and an aquaponic crop, it seems to be clear that aquaponic crops are much more efficient (12). An aquaponic crop can offer the same quality and yield with drastically lower fertilizer use and carbon dioxide emissions due to these facts (13).

The aquaponic closed system diagram, taken from here

The economics

Due to the poor nutritional characteristics of the aquaponic solutions for flowering plants, most aquaponic growers have resorted to the growing of leafy greens. A 2017 study (10) showed that profits from growing basil were more than double of those attained by growing Okra, due to the fact that basil could be grown with little additional supplementation while Okra required significant modification of the aquaponic solution to fit the plants' needs.

Due to the fact that large flowering plants require large amounts of mineral supplementation in order to be grown successfully in aquaponics, they are seldom grown in aquaponics setups. Since leafy greens eliminate the need for such supplementation, can be grown faster, and suffer from substantially less pest pressure, it is a no-brainer in most cases to grow leafy greens instead of a crop like tomatoes or peppers. However, high-value crops like cannabis might be attractive for aquaponics setups (10, 11).

Aquaponics often require economies of scale to become viable. The smallest scale aquaponic setups, like those proposed by FAO models, can offer food production capabilities to small groups of people, but suffer from a lack of economic viability when the cost of labor is taken into account (12). It is, therefore, the case that, to be as profitable as hydroponics, aquaponic facilities need to be implemented at a relatively large scale from the start, which limits their viability when compared with hydroponic setups that can offer profitability at lower scales. As a matter of fact, this 2015 study ([15](#)) showed that most aquaponic farms were implemented at relatively small scales and had therefore low profitability values.

Nonetheless, aquaponics does offer a much more sustainable way to produce food relative to conventional hydroponic facilities and does offer economic advantages, especially in regions where low water and fertilizer usage are a priority ([14](#)).

Which one is best then?

It depends on what your priorities are. If you want to build a setup with few uncertainties that can deliver the most profit at the smallest scale, then hydroponics is the way to go. Aquaponic setups have additional complexities, uncertainties, needs of scale, and limitations that hydroponic crops do not have. Building a hydroponic commercial setup is a tried-and-tested process. Hydroponics offers predictable yields and quality for a wide variety of plant products. There is also a wide industry of people who can help you achieve this, often with turn-key solutions for particular plant species and climates.

On the other hand, if you want to build a setup that is highly sustainable, has as little impact as possible on the environment, has very low fertilizer and water use and can deliver the same or better quality as a hydroponic setup, then aquaponics is the road for you. Aquaponics has significantly lower impact – as it reduces the impact of both plant growing and fish raising – and can deliver adequate economic returns if the correct fish and plant species are chosen.

In the end, it is a matter of choosing which things are most important for you and most adequate for the circumstances you will be growing in. Sometimes, limited fertilizer and water availability, coupled with higher demand for fish, might actually make an aquaponic setup the optimal economic choice versus a traditional hydroponic setup. However, most of the time a purely economic analysis would give the edge to a hydroponic facility.

If you are considering building an aquaponic system, a decoupled system that produces Tilapia and a deep water culture system producing dark leafy greens seems to be the most popular choice among commercial facilities.

Which do you think is better, aquaponics or hydroponics?

The ultimate EC to ppm chart and calculator

Electrical conductivity (EC) meters in hydroponics will generally give you different types of readings. All of these readings are conversions of the same measurement – the electrical conductivity of the solution – but growers will often only record one of them. The tools presented in this page will help you convert your old readings from one of these values to the other, so that you can compare with reference sources or with readings from a new meter. In this page you can figure out the scale of your meter, convert from ppm to EC and from EC to ppm.

The TDS reading of different meters will be done on different scales, so it is important to know the scale of your meter in order to perform these conversions. These scales are just different reference standards depending on whether your meter is comparing the conductivity of your solution to that of an NaCl, KCl or tap water standard. To learn more about how TDS scales work I would suggest you watch my youtube video on the subject. **To compare the readings from different meters, always compare the EC (mS/cm) reading, do not compare ppm readings unless you are sure they are in the same scale.**

My go-to EC meter recommendation is the Apera EC60

To figure out the scale of the meter, measure the EC (mS/cm) and TDS (ppm) of the exact same solution with your meter. After this, input the values in the first calculator below. You can then use this scale value to convert between EC and ppm using the other two calculators below. If you already know the scale of your meter you can use the other two calculators and skip the first step. The meter scale will usually be 500, 600 or 700.

Figure out the Scale of the Meter

TDS (ppm) reading:

EC (mS/cm) reading:

Calculate

Meter scale:

Convert ppm to EC

TDS (ppm) reading:

Meter scale:

Calculate

EC in mS/cm:

Convert EC to ppm

EC reading mS/cm:

Meter scale:

Calculate

TDS (ppm) reading:

Create a table for reference

Meter scale:

Generate Table

If you would like to learn more about EC readings in hydroponics I would suggest reading the following posts on my blog:

- [Comparing the conductivity of two different solutions]
- [Improving on HydroBuddy's theoretical conductivity model, the LMCv2]
- [FAQ – Electrical Conductivity (EC) in Hydroponics]

Never fail with ebb and flow hydroponic systems

Ebb and flow or "flood and drain" systems, are some of the most popular systems built in hydroponics. These are low cost, can host a large number of plants, and can generate good results, reason why they are a preferred choice for both new and experienced hydroponic growers. However, there are a substantial number of issues that can come up in these systems, both due to the different ways they can be built and because of failures in their management. In this post, I am going to give you some tips on the construction and management of ebb and flow systems so that you can minimize the chances of failure when building your own hydroponic setup of this kind. For some basics of how an ebb and flow system is set up, I advise you to watch this video.

Ensure full drainage

A common mistake when building a flood and drain system is to have incomplete drainage of the nutrient solution. Make sure you have a setup that allows for complete drainage of the solution as soon as a certain level is reached, and always stop pumps as soon as the return of the solution starts. It is quite important to also ensure that as little solution as possible remains at the bottom of your flood and drain trays or buckets, as plants sitting in puddles of water can be a recipe for disease and a very good environment for pests to develop. A very simple system I built in 2010 had the problem of never being able to efficiently drain, which caused substantial issues with the plants as root oxygenation was never as good as it should have been.

Typical flood and drain table with plants in media on top of the table.

Fast cycle speed

Ideally, you would want the flood and drain cycle of an ebb and flow system to be as fast as possible. Also, the cycles should not take more than 15 minutes, from starting to flood the growing table to completely draining the system. For this, you need to have an adequately sized pump for the volume of your table that needs to be filled (total volume minus volume taken up by plants and media). If you want to use a smaller pump, you can always add some rocks to the table in order to take up volume and ensure you require to add less volume to fully flood the reservoir. Time your cycles and make sure these are as short as possible, adequately saturate the media and completely drain, as mentioned above.

The right media

A common reason why flood and drain systems are less productive is because of a suboptimal choice of media. Ebb and flow systems periodically flood the media with nutrient solution, completely saturating it with water, so media that retains too much moisture will require infrequent cycles and will be harder to time. Media like peat moss and coco are often inadequate for ebb and flow systems due to this fact, as over-saturation of the media will lead to periods of low oxygen availability for the plants. Media that drain fast generally do much better, choices such as rockwool or perlite can give much better results when compared with media that have much higher moisture retention. Since this is a recirculating setup, perlite and rockwool also have the advantage of being more chemically inert. I however do not like media that drain too fast, such as clay pellets, as these can require too frequent cycling.

Another typical ebb and flow table setup

Time irrigations with water content sensors

Your flood and drain system requires good timing of irrigation cycles in order to have optimal results. If you irrigate based on a timer, you will over irrigate your plants when they are small and will under irrigate them when they are big. Overwatering can be a big problem in these systems and it can be completely solved by both choosing the right media – as mentioned above – and using capacitive water content sensors for the timing of your irrigations. If you're interested in doing this, check out this post I wrote about how to create and calibrate your own simple setup for using a capacitive water content sensor using an Arduino. This will allow you to flood your table only when it is needed and not risk over watering just because of a timed event happening.

Oversize the reservoir

The nutrient reservoir contains all the nutrition that is used by the plants, this means the bigger this is relative to the number of plants you have, the lower the impact of the plants per irrigation event will be. Having a reservoir that has around 5-10 gallons per plant – if you're growing large flowering plants – or 1-3 gallon per plant, for leafy greens, will give you enough of a concentration buffer so that problems that develop do so slowly and are easier to fix. A large reservoir can fight the effects of plants more effectively and make everything easier to control.

Add inline UV sterilization

Disease propagation is one of the biggest problems of this type of system. Since recirculation continuously redistributes any fungal or bacterial spores among all the plants, it is important to ensure you have a defense against this problem. A

UV filter can help you maintain your reservoir clean. You can run the solution through the inline UV filter on every irrigation event, ensuring that all the solution that reaches the plants will be as clean as possible. Make sure you use a UV filter that is rated for the gallons per hour (GPH) requirements of your particular flood and drain system. Also read my post about [getting read of algae](), to learn more about what you can do to reduce the presence of algae in a system like this.

Typical UV in-line filter used to sterilize a nutrient solution in a hydroponic setup. These are sold in aquarium shops as well.

Run at constant nutrient EC, not reservoir volume

One of the easiest ways to manage a recirculating system, especially with an oversized reservoir, is to keep it at constant EC instead of constant volume. This means you will only top it off with water in order to bring the EC back to its starting value, but you will never add nutrients to the reservoir. This will cause your total volume to drop with time as you will be adding less volume each time to get back to the original EC. When the volume drops to the point where you have less than 50% of the original volume, completely replace your reservoir with new nutrients. This gives you a better idea of how “used up” your solution really is and how close to bad imbalances in the nutrient solution you might be. A large flowering plant will normally uptake 1-2L/day, meaning that with a reservoir sized at around 5 gallons per plant, it will take you around 2-3 weeks to replace the water.

Note that more efficient and complicated ways to manage a nutrient reservoir exist, but the above is a very safe way to do so without the possibility of toxic over accumulations of nutrients from attempts to run at constant volume by attempting to add nutrients at a reduced strength to compensate for plant uptake. Topping off with nutrients without regard for the changes in the nutrient solution chemistry can often lead to bad problems. The above approach is simple and gives good results without toxicity problems.

Change your pH according to the return pH values

Instead of watering at the normal 5.8-6.2 range, check the pH of the return on a drain cycle to figure out where you should feed. Since a flood and drain system is not a constantly recirculating system, the solution conditions do not necessarily match the root zone conditions and trying to keep the solution at 5.8-6.2 might actually lead to more basic or acidic conditions than desired in the root zone. Instead, check for the return pH to be 5.8-6.2, if it is not, then you need to adjust your reservoir so that it waters at a higher or lower pH (always staying in the 5-7 range) in order to compensate for how the root zone pH might be drifting. This can take some practice, but you can get significantly better results if you base your pH value on what the return pH of your solution is, rather than by attempting to set the ideal pH at the reservoir. You will often see that you will be feeding at a consistently lower pH 5.5-5.6, in order to accommodate nutrient absorption.

Finally

The above are some simple, yet I believe critical things to consider if you want to succeed with an ebb and flow system. The above should make it much easier to successfully run a setup of this kind and grow healthy and very productive plants. Let me know what you think in the comments below!

The value of Fulvic Acid in hydroponics

Fulvic and humic acids have been studied for decades and used extensively in the soil and hydroponic growing industries. I previously talked about the use of humic acid in hydroponics and the way in which it can improve crop results. In that post, we talked about how humic acids can improve nutrient chelation and how this can lead to improvements in yields depending on the origin and properties of the humic substances used. In this post, we are going to take a look specifically at fulvic acid substances, which are a smaller family that has potentially more valuable uses in the hydroponic space. We will start by discussing what differentiates fulvic and humic acids and what the current peer-reviewed evidence around fulvic acids tells us.

This is a model of the general type of molecule that makes up fulvic acid. Note that fulvic acid is not a pure substance, but a mixture of many substances with similar chemical properties.

Fulvic acids are not chemically pure substances, but a group of chemicals that result from the decomposition of organic matter. This process generates both humic and fulvic acids. However, fulvic acids are different from humic acids in mainly two ways. The first is that fulvic acids are soluble at both acid and alkaline pH values, and the second, is that fulvic acids generally have much lower molecular weights. Fulvic acids are therefore more soluble and are more easily accessible to plants compared to humic acids, which have much larger molecular weights. But why should we use them in hydroponics and exactly how?

Sadly, not many publications have tackled the use of fulvic acid in crops specifically. One of the few examples of reviews that touch on the matter is [this paper](), which covers most of the literature around fulvic acids before 2014. I also did a literature review myself, trying to find articles in which the fulvic acid source, application type and rate, and the results against a control without fulvic acid were clearly explained. The table below shows you the results of my search, I was able to find 10 papers overall, with a mix of root and foliar applications of fulvic acid, with a range of application rates and plant species. Almost all of these papers found positive results from the use of fulvic acid, except two papers that found either no effect or mixed results from their use.

The range of application depends substantially on the application type. Most papers that tackled foliar applications chose application rates in the 1-3g/L range, while papers that tackled root applications generally stayed in the 25-150ppm range. This is normal since foliars are generally much more concentrated than root applications. Both types of applications have different effects. Root applications are going to exercise an additional strong nutrient chelating role, while foliar applications are more likely to exert a hormonal role. A study around genetically modified tomato plants showed that plants engineered to be insensitive to IAA were also unable to respond to fulvic acid, hinting at the fact that fulvic acid has an auxin-like effect in plants.

Ref	Application Type	Crop	Application (ppm)	Effect
1	Foliar	Tomato	800-1100	yield+ number+ cracking-
2	Root	Cucumber	100-300	growth+
3	Foliar	Grapevines	500	yield+ growth+ quality+
4	Root	Pepper	25	quality+
5	Foliar	Wheat	500-1000	no effect
6	Root	Impatiens	40	yield+ flowering+
7	Foliar	Faba Beans	1500-3000	yield+
8	Root	Tomato	15-30	mixed
9	Root	Okra	1500-3000	yield+ quality+
10	Root	Potato	150	yield+

Literature search of fulvic acid related publications. The websites where you can read the articles are linked in the “Ref” column.

The effects seem to be quite positive overall, with increases in yield, quality, and flower numbers across the board. The studies above that investigated nutrient transport also showed substantial benefits when root applications of fulvic acid were used. Plants grown in a Hoagland solution showed better nutrient transport when fulvic acid substances were used in the nutrient solution. This is possibly both due to their ability to chelate micronutrients and their ability to provide an additional pH buffer at the region of interest in hydroponics (5.5-6.5). This study, shows how fulvic acid substances can have pKa values in this precise region, although their still relatively large molar mass implies that they will contribute marginally to buffering capacity, especially if used only in <100 ppm concentrations.

Fulvic acids also seem to be synergistic with several other biostimulants in the studies showed above. When tests were done with humic acids or other biostimulants, the effect of the combination is usually better than the effect of either part on its own. This means the fulvic acid might not only be a good addition on its own, but it might also contribute significantly to enhance the effect of other biostimulants used.

It is however important to note that fulvic acids do have negative effects when used in excess, reason why their application rates need to be carefully controlled. Using too much can lead to drops in yields and quality along with slower growth. If you want to start using them, it is, therefore, wise to start at the lower range of the application rates shown above and climb up as you gauge the effects. It is also important to note that – as humic acids – different sources of fulvic acid might have different effects, as the actual molecules that make up the substance will change.

A big advantage of the use of fulvic acids in hydroponics is also that their solubility is quite high, so the risk of clogging or damaging equipment is low. This is a significant advantage over humic acids, which have lower solubility and can cause problems because of this in hydroponics culture, especially if there are drops in the pH. In hydroponics, fulvic acids can also lead to additional solution stability, especially in recirculating systems, where the destruction of heavy metal chelates as a function of time can become a bigger risk.

All in all, fulvic acids represent a relatively cheap addition to a hydroponic regime that has limited risk and a lot of potential upsides. Literature research shows us that low rate applications, if anything, might just have no effect, so the risk of damage to a hydroponic crop by trying fulvic acid applications is low. The synergistic effects shown by fulvic acid are also interesting since this means that they might make other additives you are currently using even more potent. When looking for fulvic acids, make sure you check for high solubility, solubility in low and high pH, and a source that matches the sources used in the literature results you're interested in reproducing.

New to organic hydroponics? Consider these six things

Although hydroponic crops cannot usually be labeled as "organic" by official certifying authorities, like the USDA, we can create a hydroponic crop that is "organic" in spirit. We can do this if we avoid the use of traditional synthetic chemical fertilizers – meaning using only OMRI listed products – and use a growing media that mimics some of the functionality that is provided by soil. This can be quite tricky to do and can lead to substantial issues in crops, reason why it is important to be aware of the problems that can arise. In this post, I will talk about five important things to consider when trying to do an organic hydroponic crop.

The media needs to be friendly for microbes. A traditional hydroponic crop will benefit from having media that is as inert as possible. However, if you are going to be avoiding synthetic fertilizers, this means that certain functions will need to be carried out by microbes. Most importantly, microbes will carry out the conversion of protein-derived nitrogen to ammonium and then nitrate nitrogen. Peat moss and coco can be friendly media for microbes, while rocky media like rockwool, perlite, vermiculite, and sand, can be more hostile. Peat moss is my preferred media for this type of setup, as the acidification of the peat moss will also help deal with some of the chemical issues that arise through an organic hydroponic crop.

Organic hydroponics farm using a nutrient solution with an amended media

Provide a nutrient solution that is as complete as you can. Your hydroponic nutrient solution should still give your plants a fair amount of nutrition, especially nutrients that are easily soluble and can leech from the media. There are several OMRI approved soluble sources of vegetable/animal-derived nutrition that can be used to create an organic feed for your plants, such as fish emulsions and kelp extracts. There are also some valuable mineral sources that are mined that can be used, such as sodium nitrate, potassium sulfate, gypsum, and magnesium sulfate (Epsom salt). Use these sources to create a balanced nutrient solution for your plants.

Amend the media to compensate for what the nutrition solution will lack. An organic hydroponic crop will generally need to contain some form of amended media because the nutrient solution will not be able to effectively provide all the nutrients it provides in a regular hydroponic crop. The absence of synthetic salts implies that we will not be able to provide things like nitrates and phosphates in the amounts we would desire. This means that nitrogen and phosphorus will both need to be added to the media to some extent. This can be done with vegetable protein, bone meal, and rock phosphate amendments.

Keep aeration higher than you would in a normal hydroponic crop. In a normal hydroponic crop, the number of microorganisms and organic decomposition reactions in the media will be quite low. However, when we move to a setup where a significant amount of nutrition is provided by microorganisms in the root zone, aeration becomes a big issue due to the increased oxygen demand from the bacterial and fungal populations in the media. A media used for an organic hydroponic setup will usually require a substantial amount of aeration to be present. *If using peat moss, it is useful to mix it 40/60 with something like perlite or rice husks in order to improve the aeration properties of the media substantially.*

A great, yet very smelly, source of N, Fe and other micronutrients for organic hydroponics

Bad heavy metals are going to be your enemy. Plants require some heavy metals and media like peat moss will lack the amounts necessary to properly sustain plant growth. However, resist the temptation to amend the media with something like green sand or azomite – a volcanic rock – as these sources can contain very important amounts of bad heavy metals, like lead, arsenic, and mercury. Instead, it is better to use amendments that provide animal sources of metals – like blood meal – or to use an organic source of soluble heavy metals in your nutrient solution, such as the Biomin series of products. Compost teas can also be a very important source of needed heavy metals. Be very aware of bad heavy metals in your organic inputs.

Inoculate the media with the bacterial and fungal populations you need. Since bacteria and fungi are going to be your allies, you need to properly inoculate the media with healthy microbe populations. I would advise inoculating with both beneficial fungi, like Trichoderma species and also with a bacteria-containing product, such as Tribus. Compost teas can also be an important source of bacteria and fungi to colonize the plant's rhizosphere.

Although the above is by no means a complete list, it does highlight some key points when moving from a purely hydroponic setup into a hydroponic setup that will rely heavily on microbes for the release of nutrients. This is a midway approach between a soil-based approach and a complete hydroponic setup, where we are expected to provide some of the nutrition through the nutrient solution but a lot of it is also expected to come from the media itself. It can be done successfully and amazing crops can be grown with it, however, it does require you to apply the skills of both soil and hydroponic crop manager.

Is hydroponics organic? Is it better or worse?

There has been a battle raging during the past decade between soil-based organic producers and hydroponic growers, to figure out whether hydroponically produced crops can or cannot be considered for organic certification. The entire discussion centers around whether a hydroponically grown crop can in fact comply with the requirements of the USDA organic standard. Within this post, we are going to discuss why there is even a discussion, why a hydroponic crop could be considered organic, and what the arguments against such a designation currently are.

USDA Organic food coming from traditional organic based growing practices

All that is required for a crop to be considered “hydroponic” is the complete absence of soil. This means that all the nutrition required for the crop is going to come from the nutrient solution and the substances that are put within this solution can or cannot comply with the USDA requirements for the “organic” label. Some substances like heavy metal chelates, potassium phosphates, and most nitrates, are forbidden by the USDA organic designation due to their synthetic origin, and the environmental impact of their production and normal usage. However, the total impact of these substances also rests heavily on how the hydroponic crop manages them and how efficiently they are used.

A hydroponic crop could use a fraction of the water and fertilizer used by a traditional soil crop of the same area while capturing all fertilizer effluents, making it environmentally more sustainable than a traditional soil crop and probably worthy of some sort of designation to recognize this fact. A hydroponic crop grown with traditionally produced synthetic fertilizers, that has absolutely no fertilizer dumping of wastewater to the environment and uses no synthetic pesticides on products has a low environmental impact and produces food of very high quality. Hydroponic crops can also use land that would otherwise be unusable by traditional soil-based methods, expanding the area that could be used for healthy and sustainable food production.

However, the defendants of the organic designation argue that it is not only about what is being produced and how it is being produced but where it is being produced. The argument is that the organic designation and requirements have specific provisions about soil sustainability and soil building, that a hydroponic crop could not possibly comply with. They argue that part of the spirit of the organic designation is to make growing in soil more sustainable and that hydroponically grown crops simply cannot do this because they completely lack any soil or any soil building process.

Both hydroponic and traditionally designated organic crops can produce food that is healthy, pesticide-free, and sustainable. Hydroponic crops can do this on land that is not traditionally arable and can do so at astonishingly high efficiencies. Therefore, it would be fair to provide hydroponic crops that are evaluated to be sustainable and grown over non-arable land, an organic designation, since they comply with the spirit of what, I believe, the people who buy organic want, which is to have foods that are produced in a sustainable manner, with little impact on the environment. If the use of synthetic fertilizers is a concern, a requirement to meet this designation could also be the use of the same array of inputs available to traditional organic growers. This is harder to achieve, but still viable within the hydroponic production paradigm.


Some hydroponic farms can be very sustainable. Farms coupling hydroponics with fish production – known as aquaponics – can make use of no synthetic fertilizers at all.

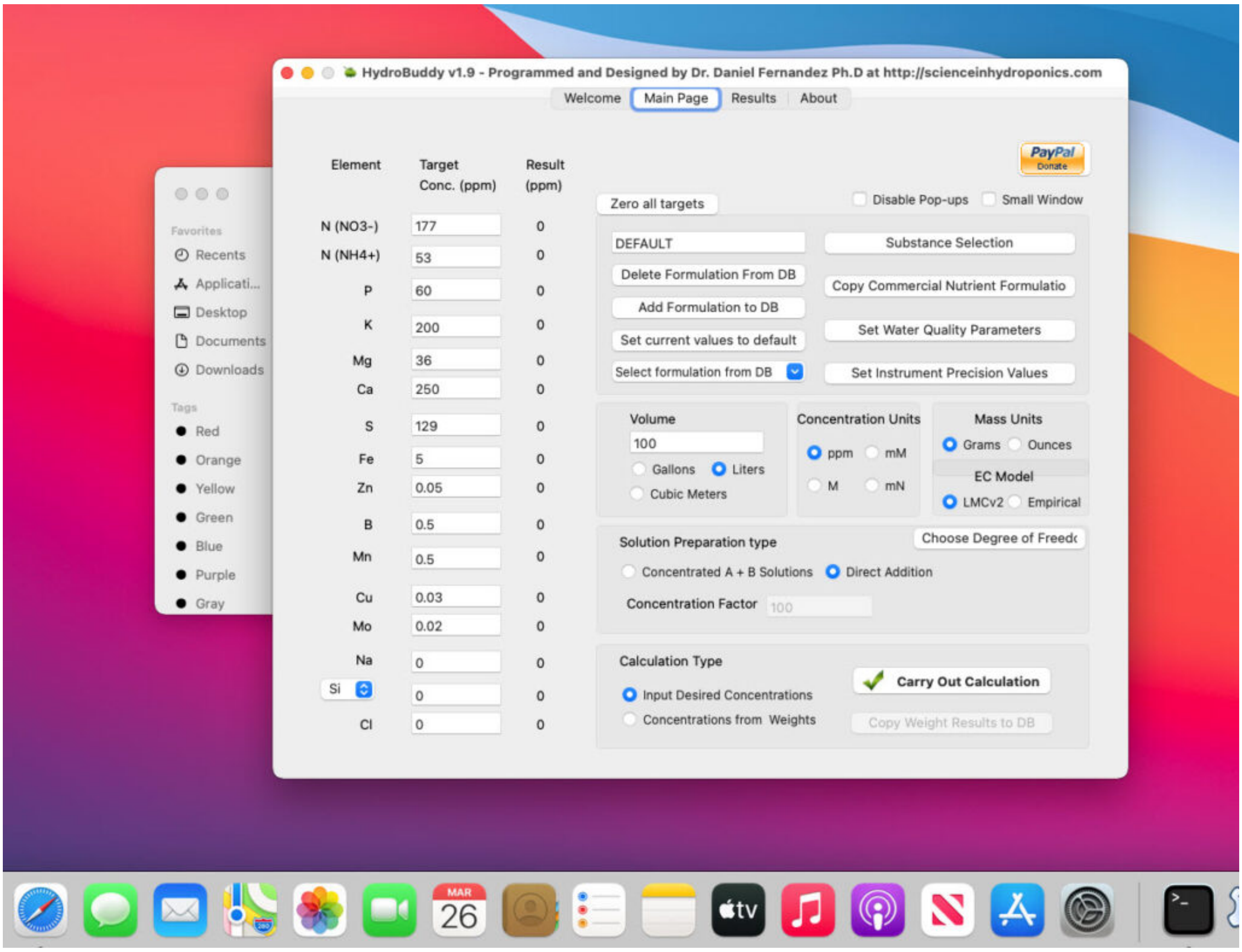
Recently, hydroponic growers have won battles in California about being granted an organic designation, however, because of the large amount of money that the organic designation carries – allowing growers to charge a big premium for items designated as organic – the organizations of soil-based organic growers are going to continue to fight this as much as they can. Organic grower organizations have even fought the potential for an independent "organic hydroponic" designation (see here), as they say, this might be confused with the normal "organic" designation and negatively affect their products.

Not all hydroponic crops are environmentally sound though. Many of them can be incredibly polluting and can make inefficient use of both water and fertilizer resources. For this reason, a designation is required to distinguish those that are sustainable from those that are not. If the USDA organic designation requirements are adjusted to accommodate for the potential for highly sustainable hydroponic crops grown on non-arable land, this would be a huge step in giving customers a clear way to tell products apart.

Hydroponic crops can be sustainable, have a low impact, and produce very high-quality, nutrient-rich food with no pesticides. They can make more efficient use of land, water, and non-synthetic fertilizers than soil-based crops do. However, the fact is that few of them really meet these criteria, because there is no designation they can achieve that would make this worthwhile from a commercial perspective. So while they are not organic at the moment, giving them the possibility to be organic would be a huge step towards a more sustainable future in agriculture. It could motivate hydroponic growers to become more sustainable and embrace a lot of the practices of soil-based organic growers.

HydroBuddy v1.9, MacOS binary, new EC model, many bug fixes and more!

Today I am releasing a new version of HydroBuddy (v1.9) which contains many suggested and needed improvements from the previous version of the software. In this post I want to discuss the changes within this release and how they will affect the way things are done in the program. Some big changes have been implemented so make sure you go through the list below if you want to use this new version. **Thanks to all of you who contributed your suggestions about HydroBuddy and/or reported bugs to me.**



One of the biggest changes in this release, the return of precompiled MacOS binaries.

Here is the list of changes in this version:

- A MacOS binary compiled in Big Sur 11.0.1 has been released.
- Ability to make any formulation the “default” formulation. This selected formulation is loaded when the software is started.
- The LMC conductivity model has now been replaced with LMCv2 which is an important improvement. See [here]() to learn more. The LMCv2 model now adjusts conductivity based on each specific ion’s charge and the overall ionic strength of the solution. It now includes no arbitrary terms.
- The treatment of liquids/solids in the program has now been changed. Instead of specifying liquid or solid (and the program having to make assumptions) users can now

select whether the percentages and substance amounts are going to be either in g and w/w% or in mL and w/v%. This should simplify the interpretation of results and the addition of substances.

- An additional column has now been added in the results page to specify the unit of the amount being calculated. When a user wants a substance’s contribution to be calculated in mL, the appropriate unit will be shown here.
- When adding a new substance, all fields are reset to null values (previously the program kept the values from previously opened/updated substances).
- Density has now been eliminated as a variable used in the program since it is not needed if there is no cross between w/w% and w/v% calculations. It is only kept in the “Copy commercial nutrient formulation” dialogue.
- An error where P and K were mixed up in the product comparison window of the “Copy commercial nutrient formulation” function has now been fixed.
- The wording of options in the “Substance selection” dialogue has been changed so that the buttons better describe what they do. For example the “Delete” button has now been changed to “Do not use”.
- Two buttons have been added next to the EC model prediction in order to allow users to increase or decrease the EC by adjusting all nutrient concentrations by +5%/-5%. This will allow you to see how nutrient concentration changes affect conductivity in a straightforward manner.

The above modifications are now committed to the github repository as well. Feel free to take a look if you’re interested in how any of the above variations were coded into the program.

Improving on HydroBuddy's theoretical conductivity model, the LMCv2

Hydrobuddy's theoretical conductivity estimates have never been good. As I discussed in a previous post, the program uses a very simple model based on limiting molar conductivities to calculate the EC. The software knows how much each ion conducts when it's all by itself, so it adds all these conductivity values multiplied by the concentration and assumes there are no additional effects. The conductivity values resulting from this assumption are very large – because there are effects that significantly reduce the conductivity of ions at larger concentrations – so HydroBuddy just cuts the estimation by 35% hoping to reach more accurate values. This works great for some cases, but very badly for others.

The reason why this happens is that the actual conductivity contribution of some ions decreases more drastically as a function of concentration and due to the presence of other ions compared to others. This means that we need to account for these decreases in conductivity in an ion-specific way. One way to approach this, is to forget about theoretical approximations and just create an empirical model that uses experimental data. This is what I did when I created the empirical model that is present in HydroBuddy from v1.7. This model works really well, provided you are using the exact list of salts that were used to create the model and you stay within the boundaries of concentration values that were used to create it.

1) $EC = \sum_i \Lambda^0_{m,i} (\gamma_i)^\alpha c_i$

2) $\alpha = \begin{cases} 0.6 / |z_i|^{0.5} = const & \text{if } I \leq 0.36\,|z_i| \\ \sqrt{I} / |z_i| & \text{otherwise} \end{cases}$

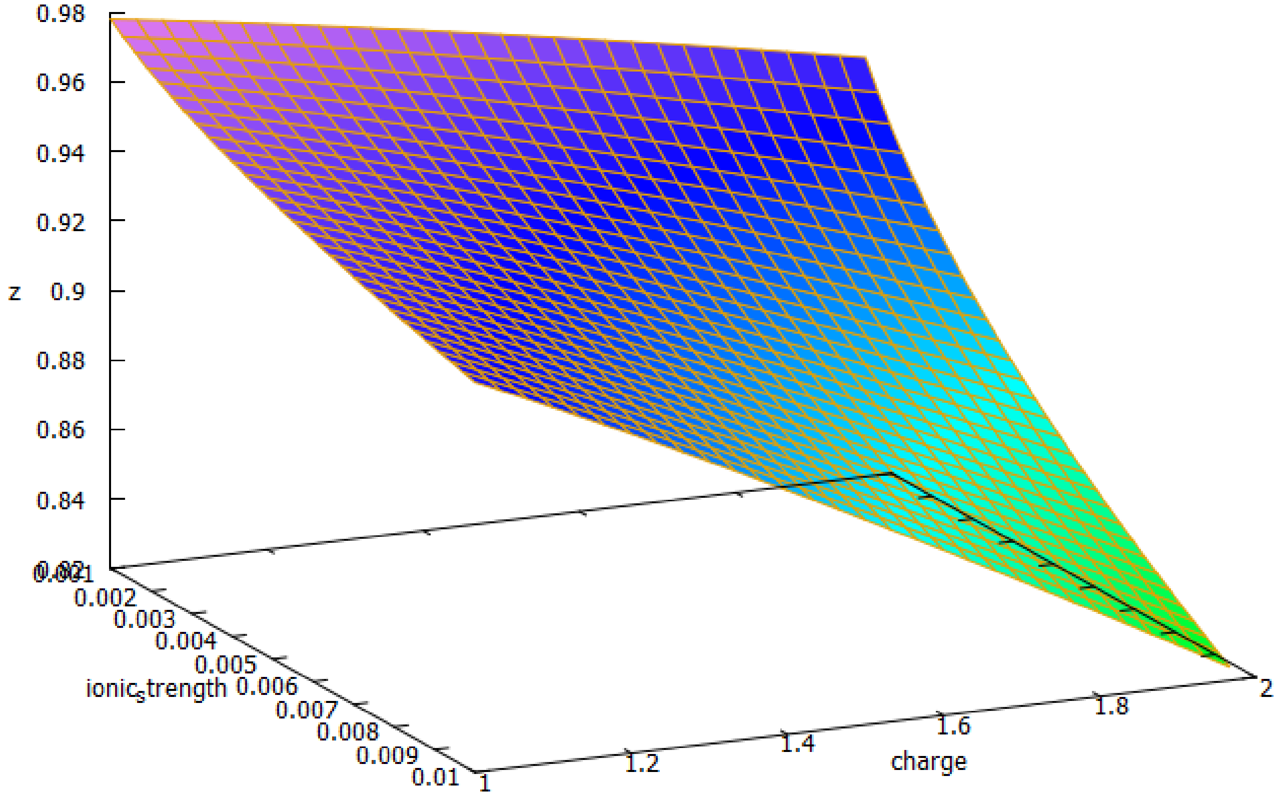
3) $\ln \gamma_i = -(\ln 10)\, A z_i^2 \sqrt{I}$

4) $$EC = \sum_i \Lambda^0_{m,i} \left(e^{-0.7025148 z_i^{1.5} \sqrt{I}} \right) c_i$$

Equations 1-3 were taken from here. I have then used these equations to derive equation 4, which is going to be the new LMCv2 model for HydroBuddy from v1.9. Where $\Lambda^0_{m,i}$ is the limiting molar conductivity of each ion, z_i is each ion's charge, I is the ionic strength of the solution and c_i is the molar concentration of each ion..

This experiment-based solution can be great. It is in fact, a technique I've used to create custom versions of HydroBuddy for clients who want to have high accuracy in their EC estimations within the salts that they specifically use. The process is however cumbersome and expensive, my wife and I – both of us chemists – do all the experimentation, and it generally requires an entire day, preparing more than 80+ solutions using high accuracy volumetric material, to get all the experimental data. It is also limited in scope, as any salt change usually requires the preparation of a substantial number of additional solutions to take it into consideration.

It would certainly be great if we could create a better, fully theoretical, conductivity model. Diving into the literature and programs used for conductivity-related calculations, I found a program called Aqion that implements a more accurate model compared with HydroBuddy's LMC model. You can read more about their approach here. They use the limiting molar conductivities but introduce additional terms to make ion-specific corrections that are related to both ionic charge and ionic strength. The ionic charge is the electrical charge of each ion, for example, +1 for K^+ and +2 for Fe^{+2}, etc. The ionic strength is the sum of the molar concentration of each ion times its charge.



3D plot of equation 4 showing the magnitude of the correction factor (z) as a function of charge and ionic strength.

The plot above shows you how this correction factor affects a solution as the ionic strength and charge of the ions change. As a solution gets more diluted, the equation approaches the sum of the conductivities at infinite dilution. Conversely, as the solution becomes more concentrated or the ion charge becomes higher, the drop in the conductivity becomes more pronounced. These are both phenomena that are in-line with experimental observations and much better reflect how conductivity is supposed to change when different ions interact in solution.

The above equation provides us with a more satisfactory theoretical estimation of conductivity compared to the current HydroBuddy LMC model. The new model is able to implement correction factors on a per-ion basis and also changes the magnitude of these corrections depending on how concentrated the solutions are. This new model will be implemented to replace the current LMC model in HydroBuddy v1.9, which will be released in the near future. This should provide significantly more accurate estimates of conductivity for the preparation of hydroponic solutions.