Standard hydroponic formulations from the scientific literature

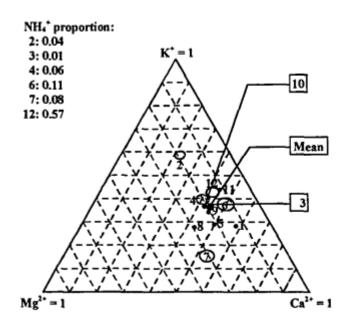
When researchers started looking into growing plants without soil, they started to look for mixtures of nutrients that could grow plants successfully so that these formulations could be used to study other aspects of plant physiology. If you have a mixture of nutrients that you know grows a plant without major issues, then you can use that as a base to study other things, for example how plants react to some exogenous agent or how changes to temperature or humidity affect the uptake of certain nutrients (see this paper for a view into the history of hydroponics and standard solutions). The establishment of these standard solutions was one of the great achievements of botanists during the twentieth century, which allowed thousands of detailed studies on plants to be carried out. In this post, we're going to be talking about these standard solutions and why they are a great place to start for anybody seeking to formulate their own nutrients.

ppm (mg/L)	1	2	3	4	5	6	7	8	9	10	11	12
K	132.93	187.28	241.24	312.79	236.15	237.33	89.54	157.57	261.57	302.23	430.08	312.79
Ca	136.27	36.07	149.09	163.52	200.39	160.31	161.11	120.23	184.76	172.34	220.43	160.31
Mg	19.69	18.71	37.19	49.34	48.61	24.31	55.90	48.61	49.10	50.55	36.46	34.03
N as NH4+	0.00	4.90	2.10	18.91	0.00	28.01	19.61	0.00	0.00	0.03	0.01	17.51
Na	0.00	0.23	1.15	0.46	0.00	0.46	0.00	2.07	0.46	0.69	8.74	0.69
Fe	36.86	2.79	4.02	0.00	1.44	1.12	1.12	5.03	1.34	1.90	7.10	0.84
Mn	0.00	0.62	1.23	0.00	0.50	0.11	0.14	0.40	0.62	1.98	2.40	0.55
Cu	0.00	0.06	0.01	0.00	0.02	0.03	0.00	0.02	0.01	0.10	0.04	0.04
Zn	0.00	0.01	0.01	0.00	0.05	0.13	0.13	0.05	0.11	0.10	0.12	0.03
N as NO3	123.82	77.46	161.50	226.63	210.10	196.09	112.75	112.05	167.80	201.28	241.62	224.11
Р	103.45	42.74	64.74	40.89	30.97	61.95	71.24	61.95	30.66	59.78	69.69	38.72
S	25.97	27.90	54.51	65.09	64.13	32.07	96.84	64.13	111.59	67.98	87.22	44.89

Cl	0.00	0.00	0.00	0.00	0.64	1.77	0.00	0.53	0.00	0.00	13.47	0.00
В	0.00	0.28	1.19	0.00	0.46	0.27	0.10	0.40	0.43	0.30	0.34	0.27
Мо	0.00	0.41	0.00	0.00	0.01	0.05	0.00	0.03	0.05	0.19	0.06	0.34

Summary of standard nutrient formulations found in this article with the concentrations translated to ppm. The numbers in the list correspond to the following: 1. Knop, 2. Penningsfeld North Africa, 3. Pennings-Feld Carnations, 4. Gravel Culture Japan, 5. Arnon and Hoagland 1940, 6. Dennisch R. Hoagland USA, 7 Shive and Robbins 1942, 8. Hacskalyo 1961, 9. Steiner 1961, 10. Cooper 1979, 11 Research Centre Soil-less culture, 12. Naaldwijk cucumber.

One of the best places to find a comparison between these standard solutions is this paper. In it, the authors explore the relationships between the different solutions and how they are similar or diverge. In the table above, you can see a summary of the elemental nutrient concentrations found in this paper for the 12 standard solutions they compare (the paper states them in mmol/L but I have changed them to ppm as these are more commonly used units in the field nowadays). As you can see, some of the older solutions miss some elements or contain much smaller amounts of them — as they were likely present in the media or other salts as impurities — while more recent standard solutions do contain all the elements we now understand are necessary for plant life.

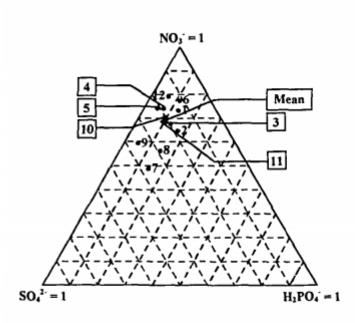


Standard solutions:

- 1. Knop
- 2. Penningsfeld N. Africa
- 3. Penningsfeld Carnations
- Gravel culture, Japan
- 5. Arnon and Hoagland
- Dennish R. Hoagland
- 7. Shive and Robbins
- 8. Hacskalyo
- 9. Steiner
- Cooper
- 11. Res. Centre Soil. Cult.
- 12. Naaldwijk, cucumber

FIGURE 1. Cation composition of the standard solutions.

Figure showing the Ca/Mg/K ratio represented in a three axis plot. Taken from the paper mentioned above.



Standard solutions:

- Knop
- 2. Penningsfeld N. Africa
- 3. Penningsfeld Carnations
- 4. Gravel culture, Japan
- Arnon and Hoagland
- 6. Dennish R. Hoagland
- 7. Shive and Robbins
- 8. Hacskalyo
- 9. Steiner
- Cooper
- 11. Res. Centre Soil. Cult.
- 12. Naaldwijk, cucumber

FIGURE 2. Anion composition of the standard solutions.

Figure showing the N/S/P ratio represented in a three axis plot. Taken from the paper mentioned above.

It is interesting to note that all of these solutions have been successfully used to grow plants, so their convergent aspects might show us some of the basic things that plants require for growth. As they highlight on the paper, the K/Mg/Ca ratio for most of these solutions is rather similar, as well as the N/S/P ratios. This means that most of these authors figured out that plants needed pretty specific ratios of these nutrients and these ratios are sustained with minor variations through the 12 solutions, developed across a span of more than 100 years. All the solutions developed from the 1940s have similar final concentrations and their starting pH is almost always in the 4-5 range, due to the presence of acid phosphate salts like monopotassium phosphate.

Nonetheless, there are several things that improved in the solutions as a function of time. The first is the inclusion of higher concentrations of all micronutrients with time, as macronutrient salt quality increased, the media sources became more inert and the need to add them to avoid deficiencies became apparent. The need to chelate micronutrients also became clear with time, as solutions starting with Hoagland's solution in the 1940s started using EDTA to chelate iron, to alleviate the problem of iron phosphate precipitation in hydroponic solutions. This is clearly shown in the table below, where the authors show how the first three solutions had almost or all of their Fe precipitate out, while the newest solutions, like Cooper's developed in 1979, had less than 5.5% of its Fe precipitated.

Standard solution	% Fe	% Cu	% Zn	% Mn
	precipitated	complexed	complexed	complexed
	as Fe ₂ (PO ₄) ₃	with chelate	with chelate	with chelate
1. Knop 1865	100	-		-
2. Penningsfeld North Africa	99.9	-	-	-
3. Penningsfeld Carnations	99.9	-	-	-
4. Gravel culture Japan	-	-	-	-
5. Arnon and Hoagland 1940	87.8	40.3	6.4	0.3
6. Dennisch R. Hoagland	4.0	97.5	97.5	0.1
7. Shive and Robbins 1942	99.9	-	-	-
8. Hacskalyo 1961	4.0	99.3	42.4	0.2
9. Steiner 1961	4.9	99.5	48.8	0.2
10. Cooper 1979	5.5	98.3	22.4	0.1
11. Res. Centre Soil. Cultures	6.9	100	99.2	7.7
12. Naaldwijk cucumber	4.5	96.5	7.8	0

This table shows the precipitated Fe and chelated portions of the micro nutrients in all the standard solutions.

The natural question when reading about standard solutions is: which one is the best one to use? Sadly, I don't think there's a simple answer. There have been multiple studies comparing standard solutions (see this one for an example). What ends up happening most of the time is that, while most of the solutions manage to grow healthy crops, one of the solutions happens to be more fit to the idiosyncrasies of the study because its conditions are better aligned with those that the authors developed the solutions under. A study revealing a solution to be better than another to grow plants under a given set of conditions does not imply that this solution will be the best one for all plants under all conditions. For this reason, the optimization of nutrient solutions to particular conditions using tissue analysis is still pursued in order to maximize yields.

My advice would be to view the above solutions as well researched starting points for your hydroponic crops. These solutions, especially the ones developed after 1940, will do a good basic job growing your plants. If you're interested in

making your own solutions, starting with a solution like the Hoagland, Steiner, or Cooper solutions is a great way to begin making your own nutrients. Once you have a basic standard solution working for you, you can then tweak it to maximize your yield and improve your crop's quality.

The stability of metal chelates

When you get introduced to hydroponics and nutrient solution chemistry, one of the first concepts that you learn is chelation. A chelate is a molecule formed by a metallic ion and a chelating agent — which is also referred to as a ligand — where the metal ion is wrapped around very tightly by this ligand. The job of the chelating agent is to keep the heavy metal ion shielded from the environment, allowing it to exist in solution without forming potentially insoluble compounds that will take it out of the nutrient solution. However, these chelates can be unstable or too stable, both of which can hinder the availability of the nutrient to plants. In this post, we're going to talk about what determines the stability of a metal chelate and how you can know if a given chelate will be able to fulfill its job in a hydroponic environment.

$$M + L \longrightarrow ML$$

$$Kb = \frac{|ML|}{(|M| \times |L|)}$$

A simplified view of the chemical equilibrium formed |M| refers to the concentration of the free metallic ion, |L| the ligand concentration and |ML| the chelate concentration. Charges are omitted for simplicity.

Since chelates are formed by the reaction of a metallic ion most commonly a cation — which a ligand, a chemical equilibrium is established between the free metallic ion, the ligand, and the chelate. Every second, there are lots of chelate molecules being formed from reactions between metallic ions and ligands, and free metallic ions and ligands are being formed from the disassembly of the chelate. The process is in equilibrium when the rates of assembly and disassembly are the same. The equilibrium constant — also known as the stability constant or Kb — tells us how displaced this equilibrium is towards the product (in this case the chelate). When the Kb value is large, the concentration of the chelate equilibrium is very large, while when Kb is small, the opposite is true. Since these numbers are usually very large for chelates, we express them as pKb which is -Log(Kb). These constants depend on temperature, but their values are independent of other chemical reactions. However, things like pH can affect the concentration of ligand or metal cation, which can affect the concentration of chelate, since the equilibrium constant's value remains the same.

	Al(III)	Ва	Ca	Co(II)	Cu	Fe(II)	Fe(III)	Hg	Mg	Mn	Ni	Sr	Zn
Acetic acid		0.39	0.53	2.24				3.7d	0.51		0.74	0.43	1.03
Adenine													
Adipic acid		1.92	2.19		3.35								
ADP		2.36	2.82	3.68	5.9				3.11	3.54	4.5	2.5	4.28
Alanine		0.8	1.24	4.82	8.18					3.24	5.96	0.73	5.16
b-Alanine					7.13						4.63		4
Albumin			2.2										
Arginine						3.2				2			
Ascorbic acid			0.19									0.35	
Asparagine			0									0.43	
Aspartic acid		1.14	1.16	5.9	8.57				2.43	3.74	7.12	1.48	2.9
ATP		3.29	3.6	4.62	6.13				4	3.98	5.02	3.03	4.25
Benzoic acid					1.6						0.9		0.9
n-Butyric acid		0.31	0.51		2.14				0.53			0.36	1

Casein			2.23										
Citraconic acid			1.3									1.3	
Citric acid		2.3	3.5	4.4	6.1	3.2	11.85	10.9d	2.8	3.2	4.8	2.8	4.5
Cysteine				9.3	19.2	6.2		14.4d	< 4	4.1	10.4		9.8
Dehydracetic acid					5.6						4.1		
Desferri-ferrichrysin							29.9						
Desferri-ferrichrome							29						
Desferri-ferrioxamin E				11.8	13.7		32.5				12.2		12
3,4-Dihydroxybenzoic acid			3.71	7.96	12.8				5.67	7.22	8.27		8.91
Dimethylglyoxime					11.9						14.6		7.7
0,0-Dimethylpurpurogallin			4.5	6.6	9.2				4.9		6.7		6.8
EDTA	16.13	7.78	10.7	16.21	18.8	14.3	25.7	21.5d	8.69	13.6	18.6	8.63	16.5
Formic acid		0.6	0.8		1.98		3.1					0.66	0.6
Fumaric acid		1.59	2		2.51					0.99		0.54	
Globulin			2.32										
Gluconic acid		0.95	1.21		18.3				0.7			1	1.7
Glutamic acid		1.28	1.43	5.06	7.85	4.6			1.9	3.3	5.9	1.37	5.45
Glutaric acid		2.04	1.06		2.4				1.08			0.6	1.6
Glyceric acid		0.80b	1.18						0.86			0.89	1.8
Glycine		0.77	1.43	5.23	8.22	4.3	10	10.3	3.45	3.2	6.1	0.91	5.16
Glycolic acid		0.66	1.11	1.6	2.81		4.7		0.92			0.8	1.92
Glycylglycine			1.24	3	6.7	2.62	9.1		1.34	2.19	4.18		3.91
Glycylsarcosine				3.91	6.5					2.29	4.44		
Guanosine				3.2	6	4.3			3		3.8		4.6
Histamine				5.16	9.55	9.6	3.72				6.88		5.96
Histidine				7.3	10.6	5.89	4			3.58	8.69		6.63
b-Hydroxybutyric		0.43	0.6						0.6			0.47	1.06
3-Hydroxyflavone				9.91	13.2								9.7
Inosine				2.6	5	3					3.3		
Inosine triphosphate			3.76	4.74					4.04	4.57			
Iron-free ferrichrome							24.6						
Isovaleric acid			0.2		2.08								
Itaconic acid			1.2		2.8						1.8	0.96	1.9
Kojic acid	7.7		2.5	7.11	6.6		9.2		3		7.4		4.9
Lactic acid		0.55	1.07	1.89	3.02		6.4		0.93	1.19	2.21	0.7	1.86
Leucine				4.49	7	3.42	9.9			2.15	5.58		4.92
Lysine							4.5			2.18			
Maleic acid		2.26	2.43		3.9					1.68	2	1.1	2
Malic acid		1.3	1.8		3.4				1.55	2.24		1.45	2.8
Methionine						3.24	9.1				5.77		4.38
Methylsalicylate					5.9		9.77						
NTA	>10	4.82	6.41	10.6	12.7	8.84	15.87		5.41	7.44	11.3	4.98	10.45
Orotic acid				6.39c							6.82		6.42
Ornithine				4.02	6.9	3.09	8.7			<2	4.85		4.1
Oxalic acid	7.26	2.31	3	4.7	6.3	>4.7	9.4		2.55	3.9	5.16	2.54	4.9
b-Phenylalanine					7.74	3.26	8.9						
Pimelic acid										1.08			
Pivalic acid			0.55		2.19								

Polyphosphate			3		3.5	3		3.2	5.5	3		2.5
Proline						4.07	10		3.34			
Propionic acid		0.34	0.5		2.2		3.45	0.54			0.43	1.01
Purine					6.9					4.88		
Pyrophosphate			5		6.7		22.2	5.7		5.8		8.7
Pyruvic acid			0.8		2.2							
Riboflavin				3.9	<6				3.4	4.1		<4
Salicylaldehyde				4.67	7.4	4.22	8.7	3.69	3.73	5.22		4.5
Salicylic acid	14.11			6.72	10.6	6.55	16.35	4.7	2.7	6.95		6.85
Sarcosine				4.34	7.83	3.52	9.7			5.41		
Serine			1.43			3.43	9.2			5.44		
Succinic acid		1.57	1.2	2.08	3.3		7.49	1.2	2.11	2.36	0.9	1.78
(+)-Tartaric acid		1.95	1.8		3.2		7.49	1.36		3.78	1.94	2.68
Tetrametaphosphate		4.9	5.2		3.18			5.17		4.95	2.8	
Threonine						3.3	8.6					
Trimetaphosphate			2.5		1.55			1.11	3.57	3.22	1.95	
Triphosphate		6.3	6.5		9.8			5.8			3.8	9.7
Tryptophan							9					
Uridine diphosphate								3.17				
Uridine triphosphate			3.71	4.55				4.02	4.78			
n-Valeric acid		0.2	0.3		2.12							
Valine					7.92	3.39	9.6		2.84	5.37		5
Xanthosine				2.8	3.4	<2				3		2.4

This table was originally present in a website that no longer exists. The data is taken from the <u>NIST reference of heavy</u> metal complexes.

The table above shows you the pKb values for different metal ions and different ligands or chelating agents. Since the pKb scale is logarithmic, a difference of 1 indicates an order of magnitude higher stability. You can also find additional references to other stability constants in this link. These constants allow us to predict which chelates will be formed if different metallic cations and ligands are present. Let's say we have a solution that contains Ca2+ and Fe3+ and we add a small amount of sodium citrate, what will happen? Since the constant for Ca2+ is 3.5 but that of Fe3+ is 11.85, citrate will chelate around 1 billion Fe3+ ions for every Ca2+ ion it chelates. In practice, this means that all the Fe3+ that can be chelated will be, while Ca2+ will remain as a free metallic ion. However, if we have Fe²⁺ instead of Fe³⁺ then Fe²⁺ has a constant of only 3.2, which means that one molecule of Fe²⁺

will be chelated for every 3 of Ca^{2+} , meaning we will have around 25% of all the chelate formed as a chelate formed by Fe^{2+} and 75% as a chelate formed by Ca^{2+} .

We can see in this manner how chelating only one heavy metal can lead to problems. Imagine that you purchase Iron EDTA and add it to your nutrient solution, but you have added Manganese from Manganese sulfate. Upon addition, the FeEDTA chelate will disassemble to generate as much Fe²⁺ and free EDTA as dictated by the equilibrium constant and the free EDTA will then get into equilibria with all the other heavy metals, since the constant with Mn is 13.6 and that of Fe is 14.3 the ligand will redistribute itself so that it complies with all the chemical equilibria present. This means that for every 7 Fe²⁺ cations that are chelated we will have around 1 Mn²⁺ containing chelate, so you will lose around 14% of the chelated Fe in order to chelate free Manganese. That free Fe²⁺ will be unstable and precipitate out, which will shift the equilibrium and cause us to lose more of the Fe chelate. This is how competing equilibria can lead to the slow but sure depletion of available cations in solution.

With the above references and charts, you should now be able to look into any chelating agent you want to use and determine how good of a choice it is for your solution and what is likely to happen once you put that chelate in. The ligand will chelate different metals in order to comply with all the equilibrium constants, so it is up to you to add enough so that all heavy metals are satisfied or add ligands whose affinity for a given ion is so high that the others are just unable to compete for it, almost regardless of their concentration.

Six things to look for in a Hydroponic sensor data logging system

Data is key. It will help you obtain high yields and improve with each additional crop cycle. Having sensor measurements not only allows you to diagnose your crop at any given point in time but also allows you to go back and figure out what might have happened if something went wrong. With all the commercial offerings now becoming available, it is starting to become harder and harder to evaluate which data logging system might be ideal for you. In this post, I seek to share with you 5 things that I always look for when evaluating data logging systems for a greenhouse or grow room. These are all things that will enable you to store sensor data adequately and take full advantage of it, ensuring you're not handy capped by a poor starting choice.

Sensor compatibility. One of the first things that I look for is which sensors I can add and what restrictions I might have on sensors that are added to the system. I like to have systems where I can connect any 3-5V analog sensor I want. I also want to be able to connect sensors that use common protocols, like i2c sensors. I also like to know that for things like pH and EC, the boards have standard plugs I can connect to, to make sure I can replace the electrodes given to me by the company with others if I wish to do so. Freedom in sensor compatibility and in the ability to replace sensors with sensors from outside the company are both a must for me.

Expandability. Many of the commercially available data logging platforms are very restricted and can often only accommodate a

very small number of sensors. Whenever you're looking for a data logging solution that will need to be deployed on a medium/large scale, it is important to consider how this implementation can expand, and how painful it would be to make that expansion. Being able to easily add/remove sensors to a platform is key to having a flexible and robust data logging solution.



Not cloud reliant. It is very important for me to be able to use the system, regardless of whether the computers are online or not, and to have all the data that I register logged locally in some manner. Systems where an internet connection is needed for data logging or where data is not stored locally are both big show stoppers when it comes to evaluating a data logging system. There is nothing wrong with having data backed up to the cloud — this is indeed very desirable — but I want to ensure that I have a local copy of my data that can I always rely on and that logging of data won't be stopped because there is some internet connection issue. Also bear in mind that if your sensors are cloud reliant you will be left without any sort of data logging system if the company goes under and those servers cease to exist.

Connectivity of sensors is robust. In many of the more trendier new systems sensor connectivity is wireless. This can be perfectly fine if it is built robustly enough, but it is often the case that connections based on WiFi will tend to fail under environments that are filled with electromagnetic noise, such as when you have a lot of HPS ballasts. It is therefore important to consider that if you have such an environment, having most of your sensors connected using cables, or using a wireless implementation robust to this type of noise is necessary.

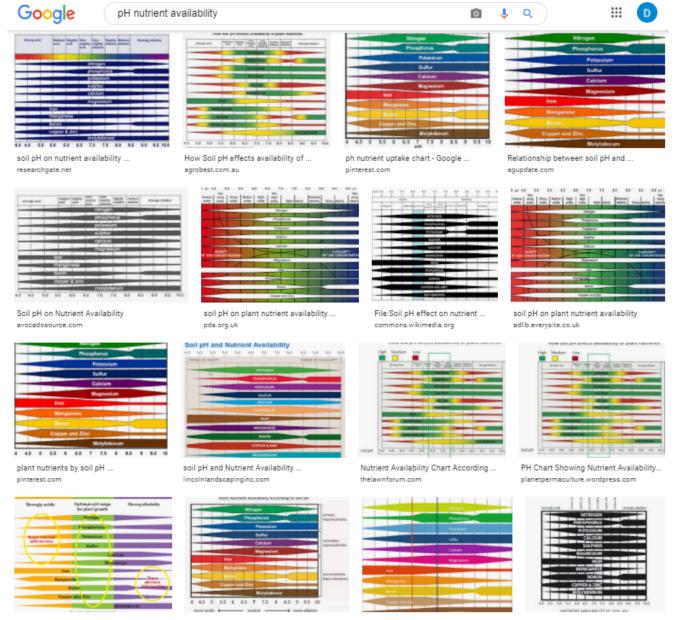
Have a robust API to directly access your data. Since I do a lot of data analyses using the data from hydroponics crops, I find it very crippling to be limited by some web interface that only allows me to look at data in some very limited ways. I want any data logging system I use to allow me to use an API to get direct access to the data so that I can implement a data structure and analysis the way I see fit. Having your data available through a robust API will allow you to expand the usage of your data significantly and it will also ensure you can backup your data or structure the database in whatever way you see fit. An example of this is sensor calibration logging and comparisons, while commercial platforms almost never have this functionality, having an API allows me to download the data and compare sensor readings between each other to figure out if some sensors have lost calibration or make sure to schedule their calibration if they haven't been calibrated for a long time.

Ability to repair. When making a data logging choice, we are making a bet on a particular company to continue existing and supporting their products in the long term. However, this is often not the case and we do not want to be left with a completely obsolete system if a company goes under and ceases to support the product they made. I always like to ensure that the systems that are being bought can continue working if the company goes under and that there is a realistic ability to find parts and replace sections of those products that might fail in the future if this were to be the case. Open source products are the most ideal because of this fact.

These are some of my top six priorities whenever I evaluate a commercial data logging solution for deployment. From the above, not being cloud reliant and having a robust API are the most important, while sensor compatibility can be ignored to an extent if the system is only being deployed for a very specific need (for which the sensors provided/available are just fine). Which of the above you give the most priority to depends on how much money you're going to be investing and how big and robust you want the implementation to be.

Nutrient availability and pH: Are those charts really accurate?

When growing plants, either in soil or hydroponically, we are interested in giving them the best possible conditions for nutrient absorption. If you have ever searched for information about plant nutrition and pH, you might remember finding a lot of charts showing the nutrient availability as a function of the pH — as shown in the image below — however, you might have also noticed that most of these images do not have an apparent source. Where does this information on pH availability come from? What experimental evidence was used to derive these graphs? Should we trust it? In this post, we are going to look at where these "nutrient availability" charts come from and whether or not we should use them when working in hydroponic crops.



A google search in 2021 showing all the different versions of the same nutrient availability plots.

Information about the above charts is not easy to come by. People have incessantly copied these charts in media, in peer reviewed papers, in journals, in websites, etc. Those who cite, usually cite each other, creating circular references that made the finding of the original source quite difficult. However, after some arduous searching, I was able to finally find the first publication with a chart of this type. It is this white paper from 1942 by Emil Truog of the University of Wisconsin. The paper is titled "The Liming of Soils" and describes Truog's review of the "state of the art" in regards to the liming of soils in the United States and the differences in nutrient availability that different pH levels

- as set by lime - can cause.

The paper is not based primordially on judicious experiments surrounding nutrient availability but on Truog's experience with limed soils and the chemistry that was known at the time. He acknowledges these limitations explicitly in the paper as follows:

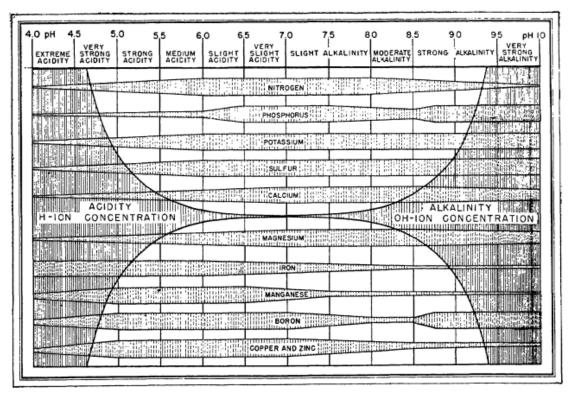
I also emphasize that the chart is a generalized diagram. Because adequate and precise data relating to certain aspects of the subject are still lacking, I had to make some assumptions in its preparation and so there are undoubtedly some inaccuracies in it. There will be cases that do not conform to the diagram because of the inaccuracies, or special and peculiar conditions that are involved, e.g., conditions that are associated with orchard crops.

"The liming of soils" by Emil Truog

It is therefore quite surprising that we continue to use this diagram, even though there have been more than 80 years of research on the subject and we now know significantly more about the chemistry of the matter. Furthermore, this diagram has been extended to use in hydroponics, where it has some very important inaccuracies. For example, Truog's decision to lower nitrogen availability as a function of pH below 6 is not based on an inability of plants to absorb nitrogen when the pH drops, but on the observations done in soil that showed that below this value, the bacteria present in soil could not effectively convert organic nitrogen into nitric nitrogen, the main source of nitrogen that crops can assimilate. In hydroponics, where nitrate is provided in its pure form, nitrate availability does not drop as the pH of the solution goes down.

Several other such assumptions are present in his diagram. Since the changes in pH he observed are associated with lime content, the drops in availability are as much a consequence

of pH increase as they are of increases in the concentration of both calcium and carbonates in the media. This significantly affects P availability, which drops substantially as the increase in pH, coupled with the increase in Ca concentration, causes significant precipitations of Ca phosphates. His diagram also ignores key developments in the area of heavy metal chelates, where the absorption of heavy metal ions can be unhindered by increases of pH due to the use of strong chelating agents.



The original pH availability chart as published by Truoug in the 1940s. It has been copied without barely any modification for the past 80 years.



Diagram from the 1935 paper by N.A. Pettinger

Reading further into Truog's paper, I found out that his diagram is actually an extension of a diagram that was created almost 10 years before, in 1935, by N. A. Pettinger, an associate agronomist at the Virginia Agricultural Experiment station. You can read this white paper here. In a similar fashion, Pettinger created a diagram that summed his experiences with different nutrients in soils at different pH values, where the pH was mainly increased or decreased by the presence or absence of lime. You can see big differences between both diagrams, while Truog includes all elements required by plants, Pettinger only includes the most highly used nutrients, leaving Zn, B, Mo, and Cu out of the picture. Pettinger also has substantially different availability profiles for Mg and Fe.

Although these diagrams are both great contributions to the field of agronomy and have been used extensively for the past 80 years, I believe it is time that we incorporate within these diagrams a lot of the knowledge that we have gained since the 1950s. I believe we can create a chart that is specific to nutrient availability in hydroponics, perhaps even charts that show availability profiles as a function of different media. We have a lot of experimental data on the subject, product of research during almost a century, so I believe I will raise up to the challenge and give it my best shot. Together, we can create a great evidence-based chart that reflects a much more current understanding of nutrient availability as a function of pH.

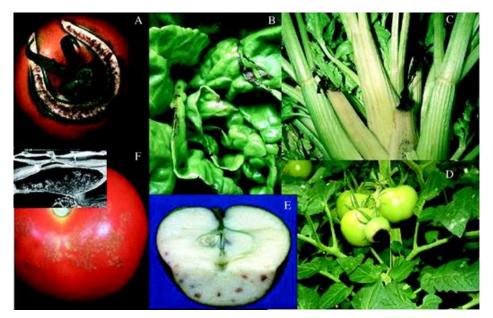
Understanding

Calcium

deficiency issues in plants

Calcium is one of the most difficult elements to properly supply to plants as its absorption is tightly linked to both chemical and environmental factors. It is very easy for growers to suffer from calcium-related problems, especially those who are growing under highly productive conditions. Issues such as bitter pit in apples, black heart in celery, blossom end rot in tomato, and inner leaf tip burn in lettuce, have all been associated with low levels of calcium in the affected tissues. In this post, we are going to discuss why this happens, how it is different for different plants, and which strategies we can use to fix the issue and get all the calcium needed into our plants' tissue. Most of the information on this post is based on these two published reviews (1, 2, 3).

Problems with Ca absorption rarely happen because there is not enough Calcium available to a plant's root system. hydroponic crops, these issues happen when ample Ca available to plant root systems and can present themselves even when apparently excess Ca is present in the nutrient solution. Concentrations of 120-200 ppm of Ca are typically found in hydroponic solutions and we can still see cases where nutrient Ca-related problems emerge. This is because issues with Ca are mostly linked to the transport of this element from roots to tissues, which is an issue that is rarely caused by the concentration of Ca available to the plants. Most commonly these problems are caused by a plant that is growing under conditions that are very favorable and Ca transport fails to keep up with other, more mobile elements. As the plant fails to get enough Ca to a specific growing point, that tissue will face a strong localized Ca deficiency and will die.



Calcium issues in different plants. Taken from this review.

When looking into a Ca problem and how to fix it, we first need to understand which plant organ is lacking proper Calcium uptake. In tomato plants, for example, blossom end rot (BER) appears when Ca fails to reach a sink organ — the fruit while in lettuce, inner tip burn develops because Ca is unable to reach a fast-growing yet photosynthetically active part of the plant. Since Calcium transport can be increased by increasing transpiration, we might think that decreasing the relative humidity (RH) might reduce BER but this in fact increases it, because transpiration increases faster in leaves, than it does in the fruit. In this case, solving the problem involves balancing Ca transport so that it reaches the fruit instead of the leaves. Pruning of excessive leaf tissue, lowering N to reduce vegetative growth, and increasing RH especially at night - can in fact help under these circumstances, where Ca deficiency develops in sink organs. Reducing ammonium as much as possible can also help, as ammonium can also antagonize calcium absorption due to its cationic nature.

In plants like cabbages and lettuce, a different picture emerges. In this case, increasing the RH leads to worse tip burn symptoms, and decreasing it significantly reduces tip burn, as Ca transport is increased by the increased leaf transpiration. This can be a viable strategy if the temperature is not too high. Under high temperatures, reducing RH leads to too much water stress, which causes other problems for the plants. In these cases, a preferred technique to reduce tip burn is to increase air circulation, which decreases both the RH around leaf tissue and the temperature of the plant due to the wind-chilling effect, this can increase transpiration rates without overly stressing plants.

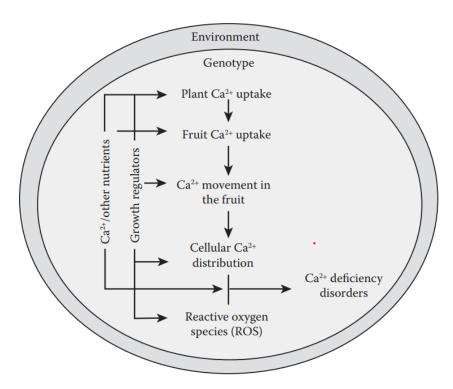


Figure 15.3 Potential mechanisms regulating Ca²⁺ deficiency disorders in fruit and vegetables.

Taken from this review.

Since in most cases these Ca issues are associated with fast growth, most measures that reduce growth will tend to reduce the severity of the Ca symptoms. Reducing the EC of solutions, reducing temperatures, and decreasing light intensity are some of the most popular mechanisms to reduce Ca problems by reducing plant productivity. These might be the most economical solutions — for example, if artificial lights are used — but it might not be favored by many growers due to the fact that it requires a sacrifice in potential yields. A potential way to attack Ca issues through growth control

without reducing yields is to use growth regulators in order to suppress vegetative growth. <u>Synthetic</u> and <u>natural</u> <u>gibberellin inhibitors</u> are both effective at this task.

A common strategy to tackle these Ca issues is to perform foliar sprays to correct the deficiency. Weekly, calcium nitrate or calcium chloride foliar sprays can help alleviate symptoms of tip burn and black heart. Spraying plants from a young age, to ensure they always have Ca in their growing tips, is key. When performing these sprays, primordially make sure all growing tips are fully covered, as Ca sprayed on old tissue won't really help the plant, as Ca cannot be transported from old to young leaves.

Disinfection of nutrient solutions in recirculating hydroponic systems

Plant growing systems that recirculate nutrients are more efficient in terms of fertilizer and water usage than their run-to-waste counter-parts. However, the constant recirculation of the nutrient solution creates a great opportunity for pathogens and algae to flourish and colonize entire crops, with often devastating results. In this post, we are going to discuss the different alternatives that are available for disinfection in recirculating crops, which ones offer us the best protection, and what we need to do in order to use them effectively. I am going to describe the advantages and disadvantages of each one so that you can take this into account when choosing a solution for your hydroponic crop.

Disinfection of recirculating nutrient solutions has been

described extensively in the scientific literature, the papers in the following links (1,2,3,4) offer a good review of such techniques and the experimental results behind them. The discussion within this post makes use of the information within these papers, as well as my personal experience while working with growers all over the world during the past 10 years.

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A slow sand filtration system will be effective at filtering most fungal and bacterial spores, but is slow. Image taken from here.

In order to kill the pathogens within a hydroponic solution, we can use chemical or non-chemical methods. Chemical methods add something to the nutrient solution that reacts with the molecules that make up pathogens, killing them in the process, while non-chemical methods will add energy to the nutrient solution in some form or filter the solution in order to eliminate undesired microbe populations. Chemical methods will often affect plants — since the chemicals are carried away with the nutrient solution — and require constant adjustments since the levels of these chemicals within the nutrient solutions need to be controlled guite carefully.

Chemical methods include sodium hypochlorite, hydrogen peroxide, and ozone additions. From these choices, both hypochlorite and hydrogen peroxide have poor disinfection performance at the concentrations tolerated by plants and are hard to maintain at the desired concentrations through an entire crop cycle without ill effects. Ozone offers good disinfection capabilities but requires additional carbon filtration steps after injection in order to ensure its removal from the nutrient solution before it contacts plant roots (since it is very poorly tolerated by plants). Additionally, ozone sterilization requires ozone sensors to be installed in the facility in order for people to avoid exposure to high levels of this gas, which is bad for human

health. In all of these cases, dosages can be monitored and controlled to a decent level using ORP meters, although solely relying on ORP sensors can be a bad idea for substances like hypochlorite as the accumulation of Na and Cl can also be problematic.

The most popular non-chemical methods for disinfection are heat treatment, UV radiation, and slow sand filtration. Slow sand filtration can successfully reduce microbe populations for fungi and bacteria but the slow nature of the process makes it an inadequate choice for larger facilities (>1 ha). Heat treatment of solutions is very effective at disinfection but is energetically intensive as it requires heating and subsequent cooling of nutrient solutions. For large facilities, UV sterilization offers the best compromise between cost and disinfection as it requires little energy, is easy to scale, and provides effective disinfection against a wide variety of pathogens if the dosage is high enough. It is however important to note that some UV lamps will also generate ozone in solution, which will require carbon filtration in order to eliminate the ill effects of this chemical. If this wants to be avoided, then lamps that are specifically designed to avoid ozone generation need to be used.

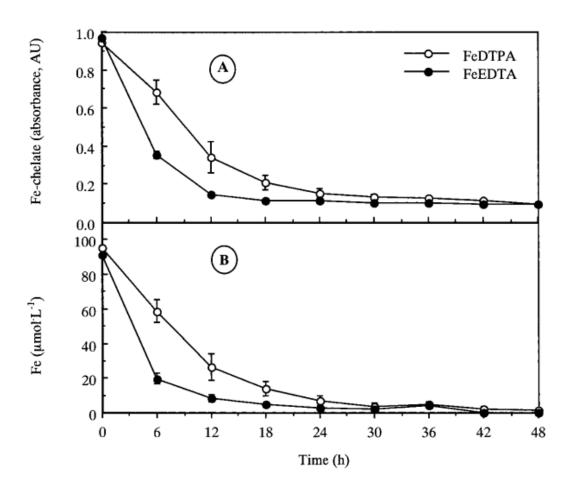


Fig. 3. (A) FeDTPA and FeEDTA determined spectrophotometrically at 260 or 258 nm, respectively, and (B) soluble Fe determined by atomic absorption spectrophotometry for a lab-prepared nutrient solution. Nutrient solutions were 5× stocks (14.28 mmol·L⁻¹ N, 17.9 μmol·L⁻¹ Fe is 1×) irradiated at 30 °C with a HID light source providing 500 μmol·m⁻²·s⁻¹(330–800 nm) measured at the surface of a 500-mL LDPE container. No absorbance was detected in solutions without Fe-chelate. Vertical bars indicate SE (n = 4). If none are shown, they fall within the dimensions of the plotting symbol.

Loss in soluble Fe as a function of UV radiation time. Taken from here. Note that this is irradiation time -not nutrient solution life — in a normal crop it will take 10x the time to accumulate the level of radiation since solution is not under radiation for most of the time.

If you want to use UV sterilization, you should carefully consider the power of the lamps and the flow rate needs in order to ensure that you have adequate sterilization. Most inline UV filters will give you a flow rate in GPH at which they consider the dosage adequate for disinfection, as a rule of thumb you should be below 50% of this value in order to ensure that the solution is adequately disinfected as some pathogens will require radiation doses significantly higher than others. You can also add many of these UV filters in parallel in order to get to the GPH measurement required by your crop. UV

sterilization also has a significant effect on all microbe populations in the environment $(\underline{5})$ so consider that you will need to inoculate with more beneficial microbes if you want to sustain microbe populations in the plants' rhizosphere.

With all these said, the last point to consider is that both chemical and UV sterilization methods will tend to destroy organic molecules in the nutrient solution, which means heavy metal chelates will be destroyed continuously, causing precipitation of heavy metals within the nutrient solution as oxides or phosphates. As a rule of thumb, any grower that uses any method that is expected to destroy chelates should add more heavy metals routinely in order to replace those that are lost. To calibrate these replacements, Fe should be measured using lab analysis once every 2 days for a week, in order to see how much Fe is depleted by the UV process. Some people have tried using other types of Fe chelates, such as lignosulfates, in order to alleviate this issue as well (6).

Five common mistakes people make when formulating hydroponic nutrients

It is not very difficult to create a basic DIY hydroponic formulation; the raw salts are available at a very low cost, and the target concentrations for the different nutrients can be found online. My nutrient calculator — HydroBuddy — contains large amounts of pre-made formulations in its database that you can use as a base for your first custom hydroponic endeavors. However, there are some common mistakes that are made when formulating hydroponic nutrients that can

seriously hurt your chances of success when creating a hydroponic recipe of your own. In this post I will be going through the 5 mistakes I see most often and tell you why these can seriously hurt your chances of success.

Failing to account for the water that will be used. A very common mistake when formulating nutrients is to ignore the composition of the water that you will be using and how your hydroponic formulation needs to account for that. If your water contains a lot of calcium or magnesium then you will need to adjust your formulation to use less of these nutrients. It is also important not to trust an analysis report from your water company but to do a water analysis yourself, since water analysis reports from your water company might not be up to date or might not cover the exact water source your water is coming from. It is also important to do several analyses per year in order to account for variations in the water composition due to temperature (which can be big). Other substances, such as carbonates and silicates also need to be taken into account in your formulation as these will affect the pH and chemical behavior of your hydroponic solution.



Failing to account for substances needed to adjust the pH of the hydroponic solution. When a hydroponic solution prepared, the pH of the solution will often need to be adjusted to a pH that is within an acceptable range hydroponics (often 5.8-6.2). This is commonly achieved by adding acid since when tap/well water is used, a substantial amount of carbonates and/or silicates will need to neutralized. Depending on the salt choices made for the recipe, adjustments could still be needed even if RO water is used. Since these adjustments most commonly use phosphoric acid, not accounting for them can often cause solutions to become very P rich with time, causing problems with the absorption of other nutrients, especially Zn and Cu. A nutrient formulation should account for the pH corrections that will be required and properly adjust the concentration of nutrients so that they will reach the proper targets considering these additions.

Iron is chelated but manganese is not. It is quite common in hydroponics for people to formulate nutrients where Fe is chelated with EDTA and/or DTPA but manganese sources are not chelated at all, often added from sulfates. Since manganese has a high affinity for these chelating agents as well, it will take some of these chelating agents from the Fe and then cause Fe phosphates to precipitate in concentrated solutions. To avoid this problem, many nutrient solutions in A/B configurations that do not chelate their Mn will have the Fe in the A solution and then the other micronutrients in the B solution. This can be problematic as it implies the Fe/other micro ratios will change if different stages with different A/B proportions are used through the crop cycle. In order to avoid this issue, always make sure all the micronutrients are chelated.

Not properly considering the ammonium/nitrate ratio. Nitrogen coming from nitrate and nitrogen coming from ammonium are completely different chemically and absorbed very differently

by plants. While plants can live with solutions with concentrations of nitrogen coming from nitrate as high as 200-250ppm, they will face substantial toxicity issues with solutions that contain ammonium at only a fraction of this concentration. It is therefore quite important to ensure that you're adding the proper sources of nitrogen and that the ratio of ammonium to nitrate is in the ideal range for the plants that you're growing. When in doubt, plants can survive quite well with only nitrogen from nitrate, so you can completely eliminate any additional sources of ammonium. Note that urea, provides nitrogen that is converted to nitrogen from ammonium, so avoid using urea as a fertilizer in hydroponic.

Not considering the media composition and contributions. When growing in hydroponic systems, the media can play a significant role in providing nutrients to the hydroponic crop and different media types will provide nutrients very differently. A saturated media extract (SME) analysis will give you an idea of what the media can contribute and you can therefore adjust your nutrient solution to account for some of the things that the media will be putting into the solution. There are sadly no broad rules of thumb for this as the contributions from the media will depend on how the media was pretreated and how/if it was amended. It will often be the case that untreated coco will require formulations with significantly lower K, while buffered/treated coco might not require this. Some peat moss providers also heavily amend their media with dolomite/limestone, which substantially changes Ca/Mg requirements, as the root system

Using VH400 sensors to build an automated irrigation setup

I have written several posts in the past about the measurement of water content in media, I have covered some very low cost and easy to use sensors that can also be plugged into Arduinos using i2c as well as some of the more accurate sensors you can get for this in hydroponics. However, there are several companies that offer more plug-and-play solutions for the monitoring of moisture in media and the setup of automated irrigation schemes using these measurements. The company Vegetronix offers moisture sensors that are insensitive to salt in media that can be plugged straight into boards that contain relays that can be used to control irrigation pumps. In this post, we will talk about these sensors, how they operate and how you could use them to automate irrigation within your growing room or greenhouse without much coding or setup efforts required. This post is not sponsored by Vegetronix and I have no association with them.



The VH400 moisture sensor

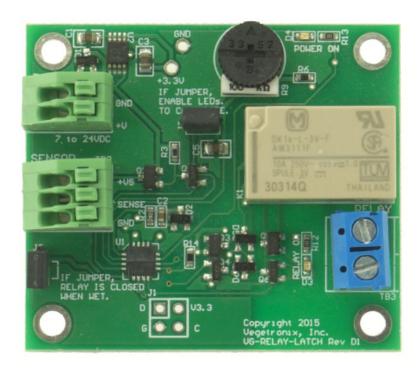
The main offering of Vegetronix in terms of moisture monitoring is their VH400 sensor, this sensor has the advantage of being completely waterproof and rugged in construction. It can be placed deep inside media — right next to the root ball — which is a huge advantage in hydroponic setups that use cocoa or peat moss and use large amounts of media per plant. The small size of the sensor also means that this will be more practical for something like rockwool compared with a sensor like the chirp, which has exposed circuity and cannot be fully submerged. In addition, the VH400 is also suitable for outdoor use. Another thing I like about these sensors is that they are analogue and can therefore be interfaced quite simply with Arduinos or other such control mechanisms, making them great for DYI. This would make them a great candidate to interface with a cricket board, which I showed in a recent post.

The technology used in these sensors is however kept secret. Given that the sensor has no exposed ceramic or metal leads, it would be fair to assume that it is capacitive in nature and probably uses a technology similar to the Chirp sensor, although it is difficult to know precisely how it carries the measurements without doing some heavy reverse-engineering of the sensors. One of its key features though is that it is unaffected by salinity, which is a key requirement for accurate measurements in hydroponics, and — given the lack of exposed metal leads — we are sure this is not a resistive sensor. Vegetronix does not seem to hold any patents on the sensor — please correct me if I'm wrong — so it is fair to assume that the technology is probably well within the well-known techniques in the field.

It is worth noting however that — although advertised as "unaffected by salinity" — it will require routine maintenance, washing with distilled water to reduce salt accumulation and recalibration to ensure it is giving accurate

moisture content measurements. As with all moisture sensors, adequate calibration and monitoring of sensors is fundamental to long term success with them. If these sensors are not maintained they will stop giving proper readings with time, especially if they are buried around the root zone of plants in hydroponic setups.

Another important point is that these are low cost sensors and have significant fabrication differences between them, proper and individual calibration of all sensors is required for proper quantitative use.



Vegetronix battery powered relay sensor

With the sensors in mind, we can now discuss the relay boards that make this choice quite attractive. The board shown above, which you can find here, is a battery-powered sensor that links to a single VH400 sensor to trigger a pump at a given moisture sensor threshold. All it takes to use this sensor is to perform a calibration procedure using the VH400 sensor and use the screw on the board to set the point where you want the relay to trigger. The board is 60 USD and the VH400 is 40 USD — at the shortest cable length — so with these two sensors you can set up a quite decent irrigation setup that is fully

automated and battery-powered, with minimal wiring required.

However, if you want a more extensive setup, you can get their relay hub, which can connect to popular cloud data services in order to send your data to the cloud while also being battery-powered and allowing for triggering of an irrigation system using multiple sensor readings or input from the cloud. Although this relay box is more expensive, at near 150 USD when you consider the battery accessories, it does provide you with a lot of additional options if you want access to remote monitoring of your moisture sensors. Since it can relay the data to third-party sites like thingspeak, it would be relatively easy for an experienced programmer to hook all that data into a central database to put it together with data from other sensors.

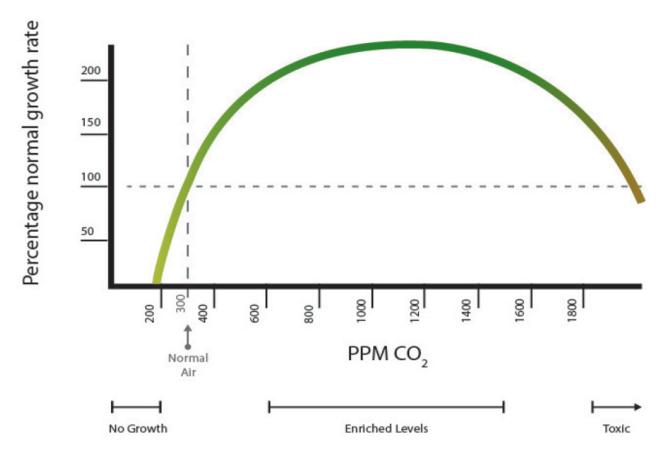
So although the Vegetronix sensors are not my preferred solution if a fully DIY setup is possible — if enough time, experienced personnel, and financial resources are available — I do believe that they make a very good value offer for those who want a decently accurate setup to monitor soil moisture content without the hassle of having to deal with the complications of a fully DIY setup. Their boards offer both super simple, low-cost solutions and more elaborate solutions for those who give more importance to data logging and monitoring. If you aren't controlling your irrigation with moisture sensors, a quick 100 USD setup of VH400+battery powered relay station is a huge step in the right direction.

Practical aspects of carbon

dioxide enrichment in hydroponics

Carbon is one of the most important nutrients a plant consumes as it the largest component of a plant's dry weight. Plants get this carbon mostly from the atmosphere — in the form of carbon dioxide — and transform it through the process of photosynthesis to create carbohydrates and other carbon-containing molecules. However, carbon dioxide concentrations in the atmosphere are relatively low (350-450 ppm) so plants that are given ample light and root nutrition — such as those in hydroponic setups — will sometimes become limited by the lack of enough carbon dioxide in the atmosphere. Carbon dioxide enrichment seeks to increase this concentration in order to remove this limitation. In today's post, we're going to talk about some of the practical aspects of CO2 enrichment in hydroponics setups, such as which concentrations to use, how to do the enrichment, and when to do it.

To dive into the scientific literature about carbon dioxide, I recommend this review from 2018, which not only summarizes a lot of the relevant literature, but contains a wide array of literature resources that can be useful for anybody who wants an in-depth look at the scientific research surrounding CO_2 enrichment. A lot of the information contained in this post was taken from this paper or its sources. I will cite specific sources when this is not the case.



Taken from the <u>Oklahoma State University website</u> on carbon dioxide supplementation which contains some great resources on the matter.

First of all, it is important to realize that carbon dioxide enrichment does not make sense under all circumstances. Plants will tend to be limited by other factors before they are limited by carbon dioxide. The first step before CO_2 enrichment is considered, is to make sure that the plants are receiving enough light (>400 μ mol/m²/s for flowering plants) and that their tissue analyses show that they are not being limited by a deficiency of any particular mineral nutrient. Plants that are either under lower light, drought stress, or nutritional deficiencies will tend to benefit significantly less from CO_2 enrichment than plants that are actually limited only by the $\mathrm{CO2}$ concentration in the greenhouse. Under some of these circumstances, CO_2 injections could lead to excessive amounts of CO_2 that might lead to actually counter-productive results. Temperature can also be a key factor in determining the

success of CO_2 enrichment, with temperatures in the upper range of ideal temperatures for a crop often leading to better results as the optimal temperature increases as a function of CO_2 enrichment (see here).

The next thing to consider is the source of carbon dioxide. The best source to use are CO2 canisters, which provide pure, on-demand CO₂ that can be easily controlled both in terms of its purity and its release into the greenhouse. Lower cost sources are usually preferable though, especially fossil fuel burners that will release CO_2 on demand. The issue with these burners is that they will release other gases into the atmosphere, like SO_2 , CO, and NO_x , which might be harmful to plants if the output from the burner is not filtered before use. These can be minimized if natural gas burners are used, as these generate the lowest amount of these side-products. Another problem with "burners" is that they will heat the environment, if this does not coincide with the greenhouse's heating needs it can lead to increases in temperature or excessive costs in climate control measures. For this reason, the timing of these "burner" cycles is critical to ensure they do not "fight" with climate control systems.

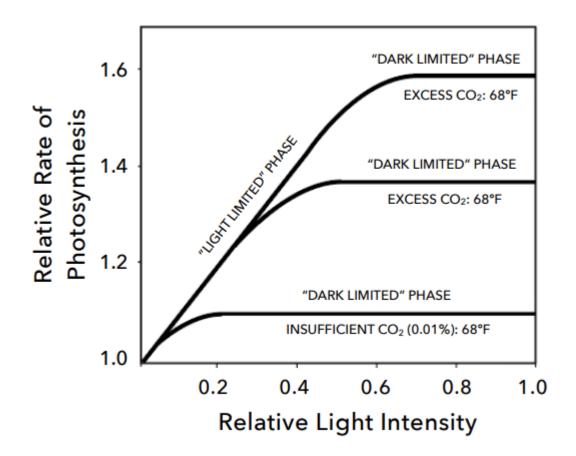
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Illustration of gas exchange rate for different temperatures for C3 plants at 330 ppm (atmospheric) and 1000 ppm (around the max that improves the PS Rate). Taken from here.

The sensors used to detect the $\mathrm{CO_2}$ and their placement will also be very important. There are mainly optical and electrochemical sensors available for $\mathrm{CO_2}$ detection. Both of these sensors need to be periodically checked against $\mathrm{CO_2}$ free gases and atmospheric $\mathrm{CO_2}$ to check their calibration. Optical sensors often require cleaning in order to remain reliable. Because of these potential reliability issues, it is often ideal to have multiple $\mathrm{CO2}$ sensors used for control and to check the values of the sensors against each other to ensure

no sensors have stopped working correctly. The CO2 distribution will usually be highest close to the ground and lower at leaf canopy, reason why sensors need to be placed around canopy height, to ensure the actual canopy concentration reaches the desirable level since this is where most CO2 will be used.

In terms of the concentration that should be held to maximize yields, research has shown that the most benefits — when these are possible — are obtained when the concentration of carbon dioxide is around 1000 ppm. Carbon dioxide is not incorporated into tissue at night and is also expected to negatively affect respiration rates, so common practice dictates that CO_2 should be reduced at night to atmospheric levels to counter this problem. A 2020 study on Mulberry attempted to establish the difference between daytime and nighttime supplementation of CO_2 and found out that all of the yield increase benefits of the supplementation were obtained when CO_2 was supplemented only during the daytime.



This image illustrates the dependence of photosynthesis on light at different levels of CO_2 enrichment. was taken from here

Regarding nutrition, carbon dioxide triggers increased demand for certain nutrients. For example, nitrogen demand increases substantially when $\mathrm{CO_2}$ supplementation is used (see here). For this reason, hydroponic crops that are $\mathrm{CO_2}$ supplemented will usually need to be fed higher amounts of nitrogen in order to avoid losing the benefits of the $\mathrm{CO_2}$ supplementation because of the inorganic nitrogen becoming a limiting factor. The carbon dioxide will increase nitrogen demand but not nitrogen absorption if the concentration is left the same, so we need to compensate for this by increasing the amount of nitrogen within the nutrient solution.

There is clearly a lot of research to be done, as optimal CO_2 supplementation involves many variables (including financial, environmental, nutritional, plant species, etc). An initial approach where the atmosphere is enriched to 1000 ppm of CO_2 with C3 plants that can take advantage of it, where nutrition, in general, is increased, temperatures are slightly increased as well and CO_2 is vented at night is bound to give satisfactory initial results. This is a good starting point for anyone looking to benefit from CO_2 enrichment.

The cricket IoT board: A great way to create simple low-power remote sensing

stations for hydroponics

When you monitor variables in a hydroponic plant where more than a few plants exist, it becomes important to be able to deploy a wide array of sensors quickly and to be able to set them up without having to lay down a couple of miles of wire in your growing rooms or greenhouses. For this reason, I have been looking for practical solutions that could easily connect to Wi-Fi, be low powered, allow for analogue sensor inputs and be more user friendly than things like ESP8266 boards that are often hard to configure and sometimes require extensive modifications to achieve low power consumption. My quest has ended with the finding of the "cricket" an off-the-shelf Wi-Fi enabled chip that fulfills all these requirements (you can find the sensor here). Through this post, I will talk about why I believe it's such a great solution to deploy sensors in a hydroponic environment. It is also worth mentioning that this post is *not* sponsored.



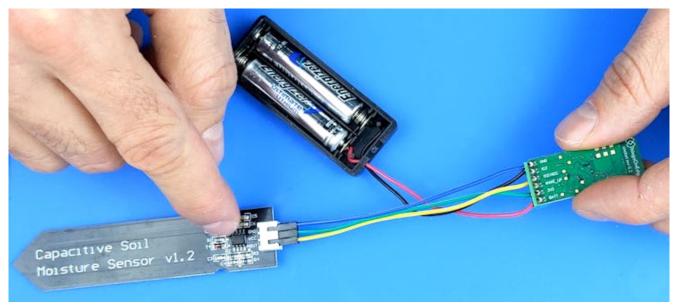
The cricket IoT board by ThingsOnEdge

When I seek to create custom monitoring solutions for hydroponic crops, one of the first requirements that comes to mind is the ability to connect through wifi effectively and be able to deliver the measurements to computers without needing wires. The cricket does this without any modifications, when you power it on it creates its own wifi hotspot that you can connect to, where you use a web interface to configure the

device to connect to the normal network.

Besides connecting to the Wi-Fi, the next problem I often face is having the ability to have a proper protocol to communicate between devices. The MQTT standard has been my preferred solution — due to how easy it is to receive and relay information — so I always seek boards that are able to easily hook up to an MQTT server once they are in a Wi-Fi network. The cricket achieves this effortlessly as well, as MQTT is part of its basic configuration, which allows you to connect it with your MQTT server and relay its data right off the bat.

One of the simplest but most powerful applications for hydroponics is to hook up a capacitive moisture sensor to a cricket board and have this relay the data to an MQTT server. You can set this up to even send the data to an MQTT server powered by ThingsOnEdge, so that you don't have to send the data to your own server. This setup can be battery powered with 2 AA batteries, it can then give you readings for several months, depending on how often you want the sensor to broadcast its readings. You can read more about how to carry out this project here.



cricket hooked to a capacitive sensor, image taken from here.

One of the disadvantages of the cricket — the main reason why it won't fully replace other boards for me — is that it only

has one analog sensor and one digital sensor input. This means that you're limited to only two sensors per cricket and you also have an inability to use more advanced input protocols, such as the i2c protocol that is used by a wide variety of sensors. If you lack i2c it means you're going to miss the opportunity to use a lot of advanced sensors, many of which I consider basic in a hydroponic setup, such as the BME280 sensors (see here why).

Although it is not a perfect sensor, the cricket does achieve two things that make it a great intro for people who want to get into IoT in hydroponics or those who want to setup a couple of low-power sensor stations with absolutely no hassle. The first is that it achieves simple configuration of both Wifi and MQTT and the second is that it simplifies the power consumption aspects, making it very easy to configure things such as sleep times, sensor reading intervals, and how often the sensor tries to relay those readings to the MQTT server. All-in-all, the cricket is a great starting point for those who want to get going with custom IoT in hydroponics with the least possible hassle.