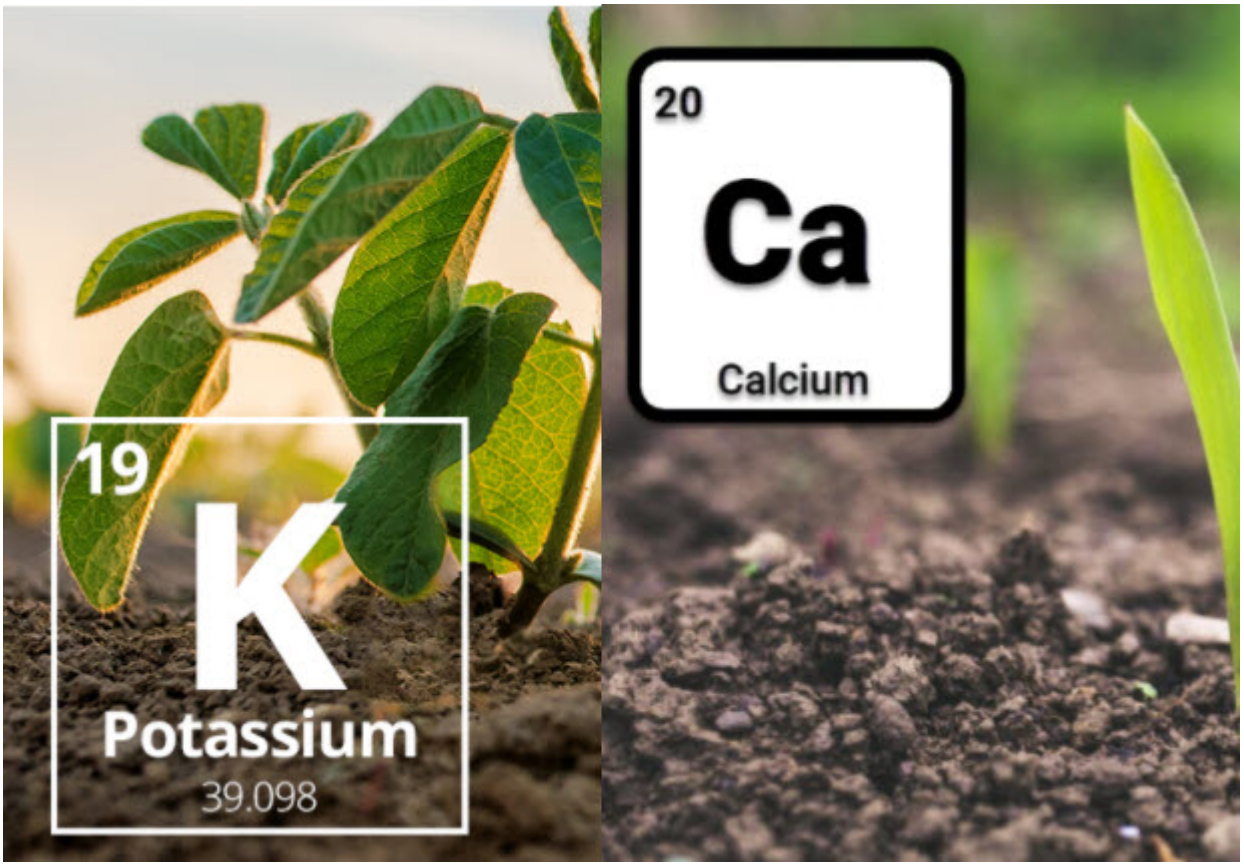
The Potassium to Calcium ratio in hydroponics

To have a healthy hydroponic crop, you need to supply plants with all the nutrients they need. One of the most important variables that determine proper nutrient absorption, is the ratio of Potassium to Calcium in the nutrient solution. These two elements compete between themselves and have different absorption profiles depending on the environment, and the plant species you are growing. For this reason, it is important to pay close attention to this ratio, and how it changes with time, in your nutrient solution. In this post, we are going to examine peer-reviewed research about this ratio and how changing it affects the growth, quality, and yield of different plant species.



Two vital elements that compete against each other. Their ratio is fundamental to maximize yields and changes depending on the plant species, environmental conditions and absolute

concentrations used

Two ions with very different properties

Potassium and Calcium are very different. Potassium ions have only one positive charge and do not form any insoluble salts with any common anions. On the other hand, calcium ions have two positive charges and form insoluble substances with a large array of anions. This creates several differences in the way plants transport and use these two nutrients.

While potassium is transported easily and in high concentrations through the inside of cells, Calcium needs to be transported in the space between cells and its intracellular concentration needs to be very closely regulated. Calcium can also only be transported up the plant – from roots to shoots – while potassium can be transported up and down as it pleases.

Calcium transport – happening around cells – is heavily dependent on transpiration, which is what causes water to flow through this space. Potassium transport is not so closely related to transpiration, as it can move directly through the inside of cells in large amounts, which means it can be actively transported through the plant in an effective manner.

Note that the above is a broad over-simplification of Potassium and Calcium transport. If you would like to learn more about this topic, I suggest reading these reviews (1,2).

Competition between K and Ca

Potassium and Calcium are both positively charged, so they do compete to a certain extent. The competition is both because they compete for anions – which they need to be paired with for transport – and for the use of electrochemical potential,

which they take advantage of to get transported across membranes. However, they do not have the same transport mechanisms, so the competition is limited.

Table 5. Interaction between EC and K:Ca ratio on nutrient concentration (g kg^{-1}) YFEL of cv. Red Mignonette 3 weeks (maturity) and 3YL 2 and 3 weeks after transplanting

EC	K:Ca	YFEL-wk 3				3YL wk 2	3YL wk 3
(dS m^{-1})		K	Ca	Mg	P	K	K
0·4	1·00:3·50	31·4	11·1	6·1	7·2	46·5	33·6
0·4	1·25:1·00	81·2	10·8	3·4	8·5	64·5	59·9
0·4	3·50:1·00	84·5	10·2	3·7	8·4	66·9	63·6
1·6	1·00:3·50	89·9	13·2	3·6	8·7	65·2	61·6
1·6	1·25:1·00	90·5	10·8	3·5	8·7	64·5	65·2
1·6	3·50:1·00	97·8	9·8	4·0	8·6	65·7	65·1
3·6	1·00:3·50	86·1	7·3	3·9	9·6	59·7	59·2
3·6	1·25:1·00	94·4	10·1	3·0	8·5	60·8	62·6
3·6	3·50:1·00	96·6	4·1	3·3	8·7	67·4	64·4
	l.s.d.[A]	9·9	2·3	0·8	0·9	5·2	4·1

Table taken from this article (3)

The table above illustrates this point. This study (3) looked into different K:Ca ratios in the growing of lettuce and the effect these ratios had on yield, tip burn, and nutrient concentrations in tissue. You can see that at low total concentrations (0.4 mS/cm EC) the K in tissue is very low when the amount of Ca is high relative to K, while at higher EC values (1.6 mS/cm EC), the K concentration remains basically unaffected, even if the Ca concentration is 3.5 times the K concentration. While Ca competes effectively with K when the absolute concentration of both is low, this competition of Ca becomes quite weak as the concentration of K and Ca increase. At very high concentrations (3.6 mS/cm EC), the potassium does start to heavily outcompete the Ca, especially when the K:Ca ratio is high (3.5x).

The above is also not common to all plants. For some plants, the competition of Ca and K actually reverses compared to the results shown above. However, it is typical for low and high absolute concentration behaviors to be different, and for the influence of K or Ca to become much lower in one of the two

cases.

Optimal K:Ca ratios

The K:Ca ratio has been studied for many of the most popularly grown plants in hydroponics. The table below shows you some of these results. It is worth noting, that the results that maximized yields, often did so at a significant compromise. For example, the highest yield for lettuce came at the cost of a significantly higher incidence of inner leaf tip burn. In a similar vein, the highest yields in tomatoes, at a 3:1 ratio, came at the cost of additional blossom end rot problems. This is to say that, although these ratios maximized yields, they often did so with consequences that wouldn't be acceptable in a commercial setup. For lettuce, 1.25:1 proved to be much more commercially viable, while still giving high yields.

Ref	Plant Specie	Optimal K:Ca
4	Rose	1.5:1
5	Tomato	3:1
6	Tomato	1.7:1
7	Marjoram	0.5:1
8	Strawberry	1.4:1
9	Cucumber	1:1
10	Lettuce	3.5:1

Optimal K:Ca – in terms of yields per plant – found for different plant species

You can see in the above results, that fairly high K:Ca ratios are typically required to increase yields. For most of the commercially grown flowering plants studied, it seems that a ratio of 1.5-2.0:1 will maximize yields without generating substantial problems in terms of Ca uptake. As mentioned above, higher K:Ca often push yields further, but with the presence of some Ca transport issues. A notable exception might be cucumber, for which the publication I cited achieved

the maximum yield at a ratio of 1:1. However, good results were still achieved for 1.5:1.

Another important point about the ratio is that it is not independent of absolute concentration. As we saw in the previous section, the nature of the competition between K and Ca can change substantially depending on the absolute ion concentrations, so the above ratios must be taken within the context of their absolute concentration. The above ratios are generally given for relatively high EC solutions (1.5-3mS/cm).

Conclusion

The K:Ca ratio is a key property of hydroponic nutrient solutions. While the optimal ratio for a given plant species cannot be known *apriori*, it is reasonable to assume that the optimal ratio will be between 1:1 and 1:2 for most large fruiting crops and flowering plants that are popularly grown in soilless culture. This is especially the case if the hydroponic solution does not have a low EC. An optimal value below 1:1 is unlikely for most plants, although exceptions do exist in certain plant families that have peculiar Ca metabolisms.

To obtain the largest benefit, it would be advisable to run trials to optimize the K:Ca ratio for your particular crop, by changing the K:Ca ratio between 1:1, 1.5:1, and 2:1. You will likely see important differences when you carry out these trials, which will be useful to determine the highest yielding configuration for your setup. To perform these variations, it is usually easiest to change the ratio of potassium to calcium nitrate used in the nutrient solution.

Have you tried different K:Ca ratios? What do you grow and what has worked for you? Share with us in the comments below!

How to use organic fertilizers in Kratky hydroponics

I've written several posts in this blog about Kratky hydroponics (for example here and here). In this method, you use a bucket, a net pot, a small amount of media, and some nutrient solution, to grow a plant from start to finish. It requires no power or interventions in the case of leafy greens or small flowering plants. However, one of the requirements of a traditional Kratky setup is the use of regular hydroponic nutrients that are created from synthetic inputs. In this post, we are going to talk about the use of organic fertilizers in Kratky hydroponics, which inputs might work, and which will be problematic.



Plant grown in a traditional Kratky setup using synthetic fertilizers

The types of organic inputs

When people talk about “organic fertilizers”, they usually refer to inputs that can be used in the growing of organically certifiable foods. The easiest way to fit this definition is to look at the inputs that are listed by organizations like OMRI. However, among OMRI-listed products, we have significant differences in where the products come from, and this makes a huge difference in whether or not we could use them in a Kratky setup.

For the purposes of this post, we can divide the OMRI-listed products into three categories. We have mined materials, which are extracted and used in their raw form from the earth. We also have animal or vegetable sourced products, which are byproducts of some animal or vegetable industry, and we have processed products, which involve some postprocessing or mixing of products in the former categories.

In the first category of products, we have things like mined magnesium sulfate, potassium sulfate, rock phosphate, sodium nitrate, or limestone. In the second category, we have things like fish emulsion, kelp extract, blood meal, and bone meal, while in the third category we have products like the Biomin series of transition metal chelates or any liquid or solid organic fertilizer blended products.

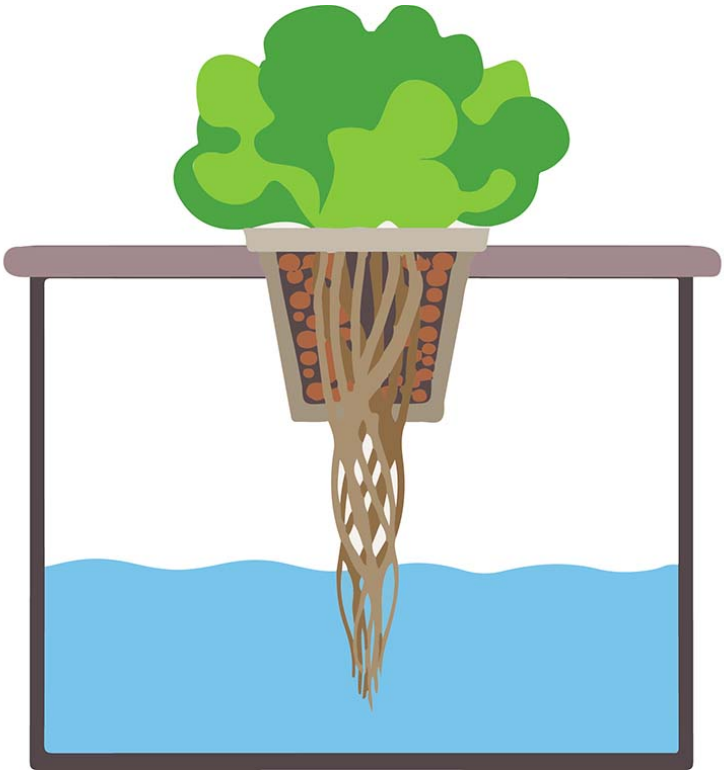
Why origin matters

The type of organic input matters, because Kratky hydroponic systems lack one important element. Oxygenation.

Since oxygen is not going to be injected into the nutrient solution, any input we use that requires oxygen for decomposition or absorption, or that requires oxygen for its proper uptake, is not going to work well. If you add any animal or vegetable product to a Kratky setup, the lack of

oxygen in the solution is going to give way to the growth of anaerobic organisms that are going to be detrimental to plant growth and will lead to root rot.

Things like blood meal – which would be great amendments in soil with good aeration where oxygen can do its job – turn into foul mixes when put into a Kratky setup. This is because a Kratky setup has a stagnant body of water that is going to turn into a very unfavorable medium for plants as soon as we add anything that creates a heavily reducing environment.



A traditional Kratky setup. Note that the solution at the bottom is stagnant and not actively oxygenated in anyway. Only the oxygen that diffuses from the air gets into the water. This is enough to keep the submerged roots alive, provided that the solution itself does not act as a sink for oxygen. In these cases, root rot is quickly experienced.

Plant roots can tolerate a relatively oxygen-deprived solution to some extent, provided that enough root mass is above the water to take in oxygen, but they cannot tolerate a solution that is rid of all oxygen by anaerobic microbial activity. This is because oxygen deprivation makes the plant more vulnerable to attack by pathogens and hinders the respiration

of plant roots, which is needed for root survival.

Which inputs can you use

In general, any input that heavily removes oxygen cannot be used as-is. This means that anything that contains plant or animal proteins, fats or carbohydrates, is not going to work well. Inputs that are heavily rich in bacteria or fungi, even beneficial ones, are also going to fail. This is because these beneficial microorganisms also require oxygen and, when they are put in a Kratky solution and die, they are digested by anaerobic organisms that can take their place.

Animal or vegetable inputs that are relatively inert in origin, such as bone meal, would not be problematic, but their ability to release nutrients is going to be limited in a Kratky solution. Mined inputs are going to be mostly fine. Soluble ones, like mined magnesium sulfate and potassium sulfate, are ideal replacements, as they are chemically identical to the synthetic ones, except for a higher content of impurities due to their raw origin. However, it will be difficult to provide enough nitrogen in an organic Kratky hydroponic setup using only this type of inputs.

A potential solution

Since the problem is mainly oxygen deprivation, we can use an organic hydroponic solution, as long as it is processed for long enough to completely eliminate the oxygen depriving capacity of the inputs. As an example, you can follow my instructions on preparing an organic hydroponic solution. This requires fermenting of the solution for a significant period of time, in order to ensure most of the oxygen requiring reactions have been carried out.

To use this solution in a Kratky setup, we would need to give it a longer period of time. We can verify that the solution is

ready for Kratky by using an ORP meter and checking that the solution is at an ORP above 300mV after removing active oxygenation for a day. This means that the solution is able to keep enough dissolved oxygen and that most of the oxygen-hungry processes in the solution are done. This might take substantially longer than the 12-15 days suggested in my original article, probably around 30 days.

Another important step is the removal of bacteria and fungi, which could be very problematic once the solution reaches the stagnant conditions of the Kratky setup. To do this, the easiest solution would be to run the solution through a UV filtering system, in order to make sure all fungi and bacteria are removed from the solution. This might sound counterintuitive, but the Kratky system conditions are not ideal growing conditions for plants and do require us to minimize oxygen sinks in the system.

Conclusion

You can run a Kratky system using an organically derived fertilizer. However, it is not straightforward, as we need to consider that a Kratky system lacks the oxygenation required to carry out a lot of the processes that are taken for granted in organic growing (such as protein decomposition). Without aeration of the solution, we need to provide an organic solution that has already exhausted its hunger for oxygen and can already provide nutrients in a manner that is available to plants. We also need to ensure we add no fungi or bacteria that can work anaerobically and attack roots in the stagnant Kratky solution conditions. We can use tools like long-term fermentation with aeration, ORP meters, and UV systems to achieve this goal.

Have you ever grown in a Kratky setup using organic fertilizers? Let us know about your experience in the comments below!

The importance of accuracy in hydroponic nutrient preparation

When you prepare your own concentrated hydroponic nutrients, you need to carry out a significant number of measurements. As a consequence, you will deviate from your intended preparation by the errors inherent to these operations. Plants tolerate a significant array of conditions, so these errors – even though sometimes quite big – are often not big enough to kill plants and are therefore ignored by growers. These errors will, however, greatly hinder your ability to optimize and evolve your crop nutrition to a higher standard. In this post, we will talk about these errors, why and how they happen, when they are important, and how you can minimize them in order to obtain more reproducible results.



The markings in buckets can carry high systematic and random errors.

Types of error

Systematic Error

There are two types of errors that happen when anything is measured. The first is systematic error, which is the error inherent to calibration problems of the instrument. For example, you might be using a 1 gallon jug to prepare concentrated nutrients and always filling the jug to a mark you made on it. This mark is not going to be 1 gallon, but

probably significantly over or under it. As long as you always use the same jug and fill to the same mark, this large deviation from 1 gallon will always be the same. As long as the measuring instrument is unchanged – meaning not recalibrated – the systematic error always remains the same in sign and magnitude.

Random Error

The second type of error relates to the randomness of the measuring process. Imagine that you used a sharpie to make the mark on the above-mentioned one-gallon jug, and you always try to measure to the same mark. The mark has some width, sometimes you will fill your jug up to the bottom of the mark, sometimes up to the top. Sometimes the surface where you place the jug where you measure will not be perfectly leveled, so the mark will be off because it will be higher at one side of the jug vs the other, etc. This error changes randomly, every time you measure. One time you might be +1%, the other -4%, etc.

Where the biggest errors happen

When you make your own hydroponic nutrients, you will be measuring two things: volume and mass. These two measurements will both carry systematic and random errors. The errors in scales are more obvious, so growers will always make an effort to get scales that are accurate enough for the measurements they want to make. For small growers, this means getting scales that can measure +/-0.01g with a decent capacity, normally 500g is fine. Buying weights to properly calibrate these scales is also recommended, in order to reduce systematic errors as much as possible.

However, always make sure you read at least 3 significant digits when making a weight measurement. This means if you need to measure 1.673485g, you need a scale that measures at

least 2 digits, so that you can measure 1.67 +/- 0.01g. This will keep your error below the 1% mark. This is why it is often common to also get a +/-0.001g scale, to measure things like sodium molybdate. You can also go around this problem by preparing more concentrated solution, as your weights become larger, with larger volumes.

Volumes however are where the largest errors are accrued. Most growers will use non-calibrated receptacles to measure volume. The fact that something has a line drawn on it with a volume marking, does not mean that this line is accurate. The systematic errors in these receptacles are usually very large because these were never intended for accurate measurements of volume. **Things like buckets, beakers, tanks, and jugs, should not be used to measure volumes**. Wide containers, like buckets and tanks, also enhance errors that relate to parallax – your ability to judge whether a level of water is at a line – so the random component of your error will be quite large.

Consequences in nutrient values

In the best cases – for jugs, buckets, and tanks – the systematic error is around 10% with a random error of +/- 5% (3 sigma). If you are preparing a concentrated solution where the final expected concentration after dilution is 200 ppm of K, then this means that your actual K value in solution will start by being 10% over or under it – depending on which way the systematic error of your volume measurement goes – and then deviate +/-5% from there. This means that you are expected to get values all the way from 170 to 230 ppm in the final solution.

This is fine as far as keeping plants alive goes. A solution with 170 ppm will keep plants alive as well as a 230ppm solution would. This is the reason why most growers don’t see an immediate need to reduce these errors. If you’re growing healthy plants and you have less or more than what you

intended, what is the problem?

How inaccuracy affects your process

There are three ways in which having inaccurately prepared solutions can affect your process. The first is that it makes you very vulnerable to changes. The second is that it makes it difficult for you to effectively optimize your setup, and the third is that it prevents others from being able to reproduce your results.

Changes in your setup can affect you deeply

Let’s say you optimized your nutrients with time and found that the optimal is 200ppm of K. In reality you have a bucket that always measures 10% less volume and you randomly deviate +/- 5% from that as well. This means that your final solutions are majorly in the 210-230 ppm range. Your trusty plastic bucket then cracks and you need to go and buy another one, you suddenly find that you’re not getting the same results. Now you have a bucket that just by chance, happens to measure the volume more accurately. You are now feeding 190-210ppm, substantially less K. You never knew that, you’re confused, you’re preparing everything the same way.

Your ability to optimize is hindered

The second problem is similar. Let’s say you prepared a batch of concentrated solution to compare feeding K at 180 ppm and K at 200 ppm. You prepare a single-stock solution to carry out the test. This bucket has a systematic error of +10% and a random error of +/-5%. For this batch, the solution happens to be 6% more concentrated than intended (+10% systematic, -4% random), so you end up with 190.8ppm and 212ppm. You find out that the 200 ppm preparation works better, so you decide to use it.

However, you run out of the stock solution you prepared for the experiment, so you prepare it again. However, you incur a different random error in this preparation – remember random errors are different every time you measure – and you end up being with a +1% random error, so a +11% total error. Your results are not as good as before, you don't know why. The reason, you're feeding 222ppm while in your previous experiment you had fed 212ppm. All while thinking you were feeding 200 ppm.

It becomes hard to share

Systematic and random errors can make effective sharing of results impractical. Imagine you have optimized your setup to the point where you're sure that the solution you prepare is the best one for a given plant under some given conditions. Then, you want to share this with another grower and tell him how to mix your formulation. This person tries it and tells you that your solution doesn't actually work the way you think. You might both be aiming for the same targets but hitting completely different numbers in reality. When sharing, it is important to share the numbers you aim for, as well as the error related to these values.

How to reduce errors

Prepare highly accurate small scale solutions

The easiest way to reduce errors when preparing hydroponic solutions is to base all preparations on small-scale experiments where the preparation can be done much more accurately, using calibrated volumetric material. Watch my videos on preparing hydroponic solutions, how to correctly prepare dilutions and how to characterize stock solutions, to learn more about how this is done.



Volumetric flasks can be used for highly accurate small scale preparations

The idea is that these small-scale preparations can tell you things such as: the amount of water you need to add for a given volume of stock solution, the expected conductivity of dilutions, and the expected density of the stock solution. Remember that salts take up volume, so to prepare 1 gallon of a concentrated stock solution you will need much less than 1 gallon of water. With this information, you can then prepare larger amounts of stock solutions, since you know the exact amount of water to add for a final volume, which you can accurately measure with a flow meter instead of having to use markings of any kind. You can then use the density measurement to check the accuracy of the preparation.

Perform fewer measurements

Every measurement you make incurs an additional error. It is

better to prepare 2 concentrated nutrient solutions than to have 10 solutions with the salts being separated because you need to make 8 fewer volume measurements. If you minimize the number of measurements that you need to do to arrive at the nutrient solution that is fed to plants, you will also minimize the error incurred in these measurements. Minimize measurements from instruments with high errors. If your volumes have much more inaccuracy than your weights, prioritize lowering the number of times you measure volume vs weights.

Conclusion

Accuracy is something to strive for. It closes no doors, only opens them. It is not about being overly fuzzy or obsessive about it, it's about using it to help you get better. Better practices, lower errors, more reproducibility, more learning. It's a virtuous cycle. Errors are always there, whether you're aware of them or not. Ignore them at your own peril.

If you have a process that is inaccurate that generates significant variations in your nutrient solution makeup, then these will be a problem, one way or another. You might be unable to judge whether changes in your crop are due to errors or due to changes, you might be unable to reproduce results and you might find yourself unable to meaningfully share results and explore with others. High accuracy is often not substantially expensive in hydroponics – instruments for accurate small-scale preparation are generally below the 200 USD mark total – and they can dramatically enhance the quality of your solutions and the conclusions you can make from experiments.

Do you prepare your own nutrient solutions? Do you know what your systematic and random errors are? Share with us in the comments below!

My Kratky tomato project, tracking a Kratky setup from start to finish

Fully passive, hydroponic setups are now everywhere. However, it seems no one has taken the time to diligently record how the nutrient solution changes through time in these setups and what problems these changes can generate for plant growth. In my Kratky tomato project, I will be closely monitoring a completely passive Kratky setup from start to finish. In this post, I will describe how this project will work, what I will be recording, and what I'm hoping to achieve. Check out the youtube video below for an initial intro to this project.

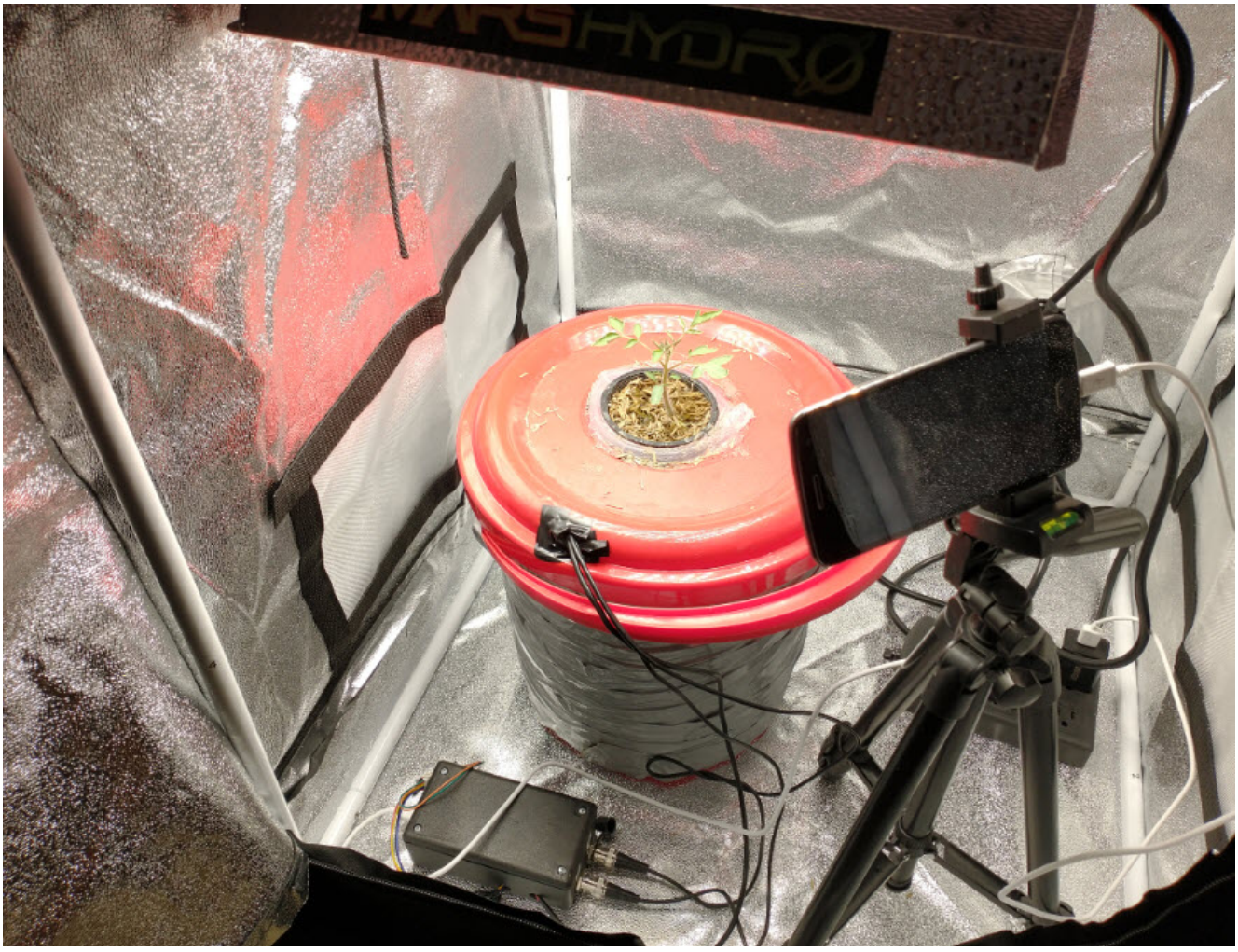
Introduction video for this Kratky project.

The goals

It is tough to grow large flowering plants using truly passive Kratky setups (read my blog post on the matter). We know this is because of issues related to their increased water uptake and the large nutrient and pH imbalances these plants create in nutrient solutions. However, I haven't found any data set that shows how these problems develop as a function of time. By measuring different variables in a Kratky setup through an entire crop cycle, I hope to gather data to help us understand what goes wrong, why it goes wrong and when it goes wrong. With this information, we should be able to develop better nutrient solutions and management techniques, for more successful Kratky hydroponic setups for large flowering plants.

The setup

The setup is a 13L bucket wrapped in duct tape – to prevent light from entering the system – with a hole at the top and a net pot containing a tomato plant. The tomato – which I have named Bernard – is an indeterminate cherry tomato that was germinated in the net pot. The net pot contains a medium consisting of 50% rice hulls and 50% river sand. The bucket has been filled with a store-bought generic hydroponic nutrient solution up to the point where it touches the bottom of the net pot. Furthermore, the bucket is placed inside a grow tent and receives 12 hours of light from a Mars Hydro TS 600 Full Spectrum lamp. The light has been initially placed around 10 inches above the plant and will be moved as needed to maintain proper leaf temperature and light coverage of the plant.



The experimental Kratky setup. You can see the project box

housing the Arduino and sensor boards at the bottom. Bernard has been growing for 2 weeks and is already showing its second set of true leaves.

The measurements

I will be monitoring as many variables as I can within this experiment. To do this I have set up an Arduino MKR Wifi 1010 that uses self-isolated uFire pH and EC probes, a BME280 sensor to monitor air temperature and humidity, and a DS18B20 sensor to monitor the temperature of the solution. I will also be using Horiba probes to track the Nitrate, Potassium, and Calcium concentrations once per day. All the Arduino's readings are being sent via Wifi to a MyCodo server in a Raspberry Pi, using the MQTT messaging protocol. The data is then recorded into the MyCodo's database and also displayed in a custom dashboard. The ISE measurements are manually recorded on a spreadsheet.



The dashboard of my MyCodo server, showing the measurements of the system as a function of time. All readings are also recorded in the MyCodo database for future reference and processing.

Furthermore, I am also taking photographs every 15 minutes – when the lights are on – using a smartphone. This will allow

me to create a time-lapse showing the growth of the plant from the very early seedling to late fruiting stages.

Conclusion

I have started a new project where I will fully record the complete development process of a large flowering plant in a Kratky setup. We will have information about the EC and pH changes of the solution, as well as information about how different nutrient concentrations (N, K and Ca) change through the life of the plant. With this information, we should be able to figure out how to modify the nutrient solution to grow large flowering plants more successfully, and what interventions might be critical in case fully passive growth is not possible.

I will continue to share updates of this project in both my blog and YouTube channel.

What do you think about this project? Do you think Bernard will make it? Let us know in the comments below!

Kinetin, a powerful hormone for flowering plants

Kinetin was the first cytokinin ever discovered. Scientists have used it extensively to stimulate cell division in tissue culture, as it is a powerful growth hormone. However, there isn't a clear understanding of the effects of kinetin in large flowering plants, reason why it hasn't been widely used as an additive in plant culture. In this post, we are going to take a look into the practical application of kinetin. We are going

to look into published research and discuss whether kinetin could be used to enhance plant yields. I will refrain from discussing the history and chemical structure of kinetin, for a basic introduction about kinetin and its history, I suggest reading this paper (1). I will also use some information contained in this review (5).

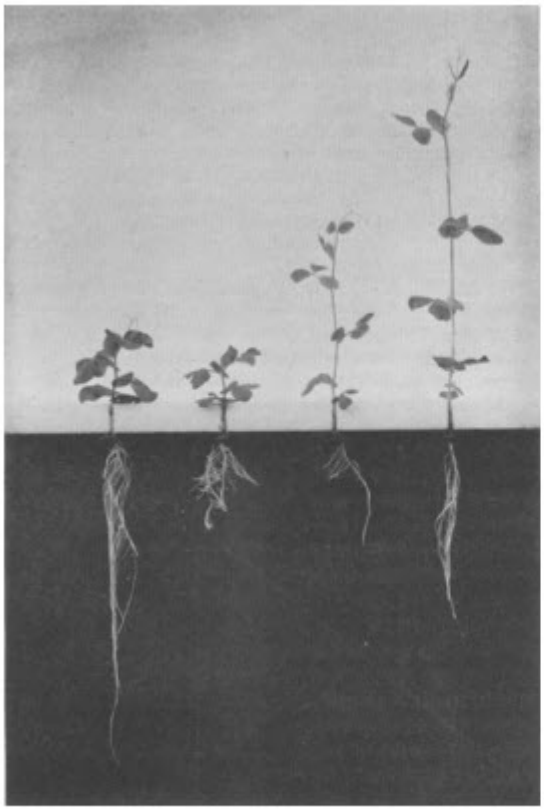


Fig. 5. Comparative inhibitory effects of kinetin and N^6-benzyladenine on the height of the 'Alaska' pea.

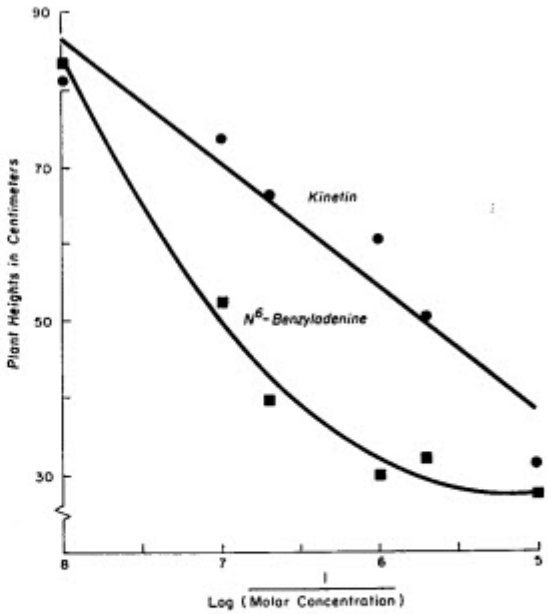


Fig. 4. Effects of kinetin and gibberellin, singly and in combination, in the solution culture root medium on internode elongation of the 'Little Marvel' dwarf pea. Left to right: control (no kinetin), kinetin 10^{-6} M, kinetin 10^{-6} M + gibberellin A_3 10^{-6} M, and gibberellin 10^{-6} M. Plants photographed after 10 days' exposure to the chemical stimuli.

Tomatoes, peas and cucumbers grown in solutions containing kinetin were significantly shorter. Root and flowering changes were also present. Taken from (2).

The effects of exogenous kinetin

In tissue culture, what kinetin does seems to be clear, it promotes cell division in the presence of auxins. However, for large plants in soilless media, the effect does not seem to be that straightforward. One of the first thorough studies of kinetin in flowering plants was done in the early 1960s (2). In this study, tomatoes, cucumbers, and peats were grown in solutions containing different concentrations of kinetin,

going from 10^{-5} to 10^{-7} molar. The researchers showed that kinetin in solution behaved like a gibberellin inhibitor, directly suppressing plant height as a function of concentration. The plants developed several root abnormalities and changes in their flowering cycle, with kinetin inhibiting flowering in tomatoes, but accelerating it in peas.

You can see in this study that the effective concentration is quite low. The range of kinetin concentrations tested goes from 0.0215mg/L to 2.15 mg/L. These values are quite small compared to the amounts of other hormones, such as IBA or NAA, generally used in plant culture. The concentration of kinetin plays a key role in its effect. A 2008 study on red goosefoot (3) shows the strong impact kinetin concentration can have. These researchers showed that low concentrations of kinetin increased bud formation and increased the height of the apical meristem, while large concentrations inhibited flowering and made the plants shorter.

The entire literature on exogenous kinetin applications is therefore split between apparently contradictory effects. Some studies show effects that are more in line with a gibberellin inhibitor, with shorter plants, while others show stimulation of shoot growth. What you get is dependent on concentration and plant species, making kinetin a hard hormone to use. Use too much and you might compromise flowering and yields, use too little and you might have undesirable elongation effects or simply no effects at all (4, 6).

Kinetin can also have an effect on the sex determination of plants. For example, kinetin induces female flowers in cannabis and can ameliorate the production of male flowers in female plants (12).

Kinetin foliar sprays

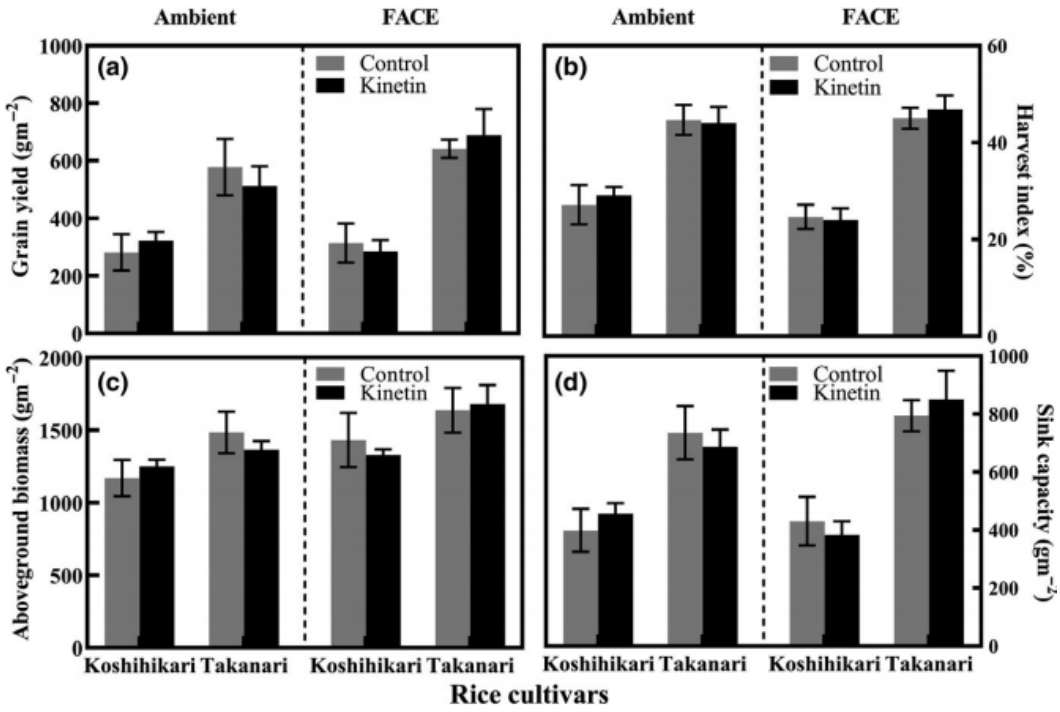
The mode of application makes a big difference as well. While

most of the root studies I read using kinetin kept their application rates below 3mg/L, many foliar studies explore kinetin application rates that are significantly higher. In this study (9), for example, they perform kinetin applications at 100 ppm. From the foliar studies I read, I found this study (7) particularly interesting. In it, kinetin applications at 2.5, 5, and 10 mg/L were done using foliar spraying on tomato, cucumber, and pepper plants.

The researchers found that the cucumbers had an excellent response to the 2.5 mg/L treatment, with taller plants, larger leaf area, and bigger yields, while they showed negative responses to the 10ppm treatment, with lower yields. While tomatoes showed a similar response, peppers gave their best results with the 10 ppm kinetin sprays. This again highlights not only that plants will respond negatively to excessive doses of kinetin, but that this response is significantly species-dependent.

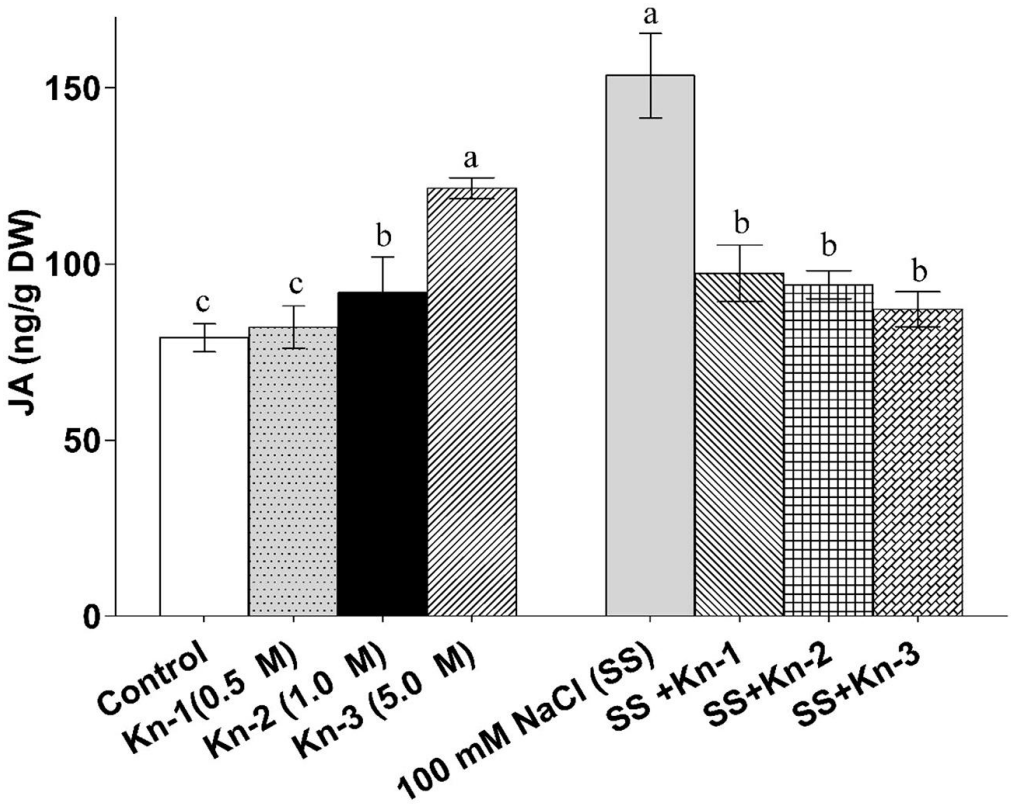
Environmental conditions

Furthermore, environmental conditions can play a significant role in the effects of kinetin. This study (8) found that kinetin could help rice plants give better yields under carbon dioxide enrichment. However, this worked only for some of the varieties of rice used. For the varieties for which it worked, kinetin applied as a foliar at 10.75 ppm was able to enhance the carbon dioxide fertilization effect.



Effect of kinetin application in several different rice cultivars with or without carbon dioxide enrichment (8)

Other environmental conditions, such as salinity stress and oxidative stress, can also play a big role in the effect of kinetin. As a strong antioxidant, kinetin can help plants deal with oxidative stress (10). It has also been tested many times as a way to deal with salinity-induced stress, for example, see this article on kinetin applications in soybeans (11). In this last study, you can see how kinetin upregulates the gibberellin biosynthesis pathway when it was actively suppressed by the high salinity. Some effects, such as the production of jasmonic acid, are actually opposite in the control and in the salinity-induced environments as a function of kinetin concentration.



Changes in jasmonic acid content for soybean plants grown with or without salt stress and treated with kinetin. Kinetin increases JA when no salt stress is present and decreases it otherwise.

Conclusion

Kinetin can be a powerful and versatile hormone in flowering plants. It can be used to achieve a variety of different effects, including making plants shorter, increasing budding sites, increasing yields, or relieving sources of stress. However, the choice of concentration, method, and application time is critical and can lead to completely opposite effects if not done correctly. Low applications tend to increase growth and leaf area, while larger concentrations will show an effect similar to a gibberellin inhibitor. However, the concentrations that work best for a given plant cannot be known before experimentation is done. However, do consider that higher concentrations consistently lead to decreases in yields.

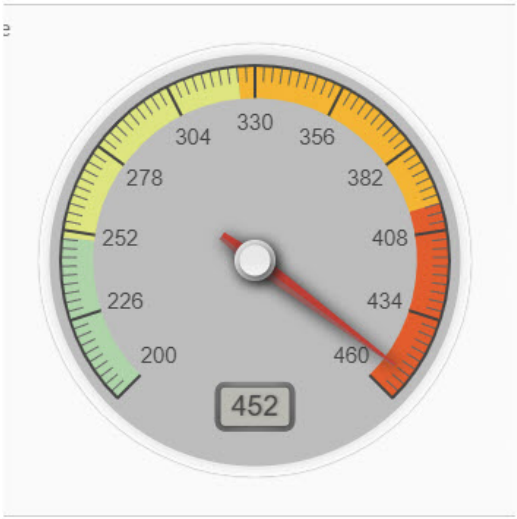
If you want to use kinetin in your crop, start with a foliar

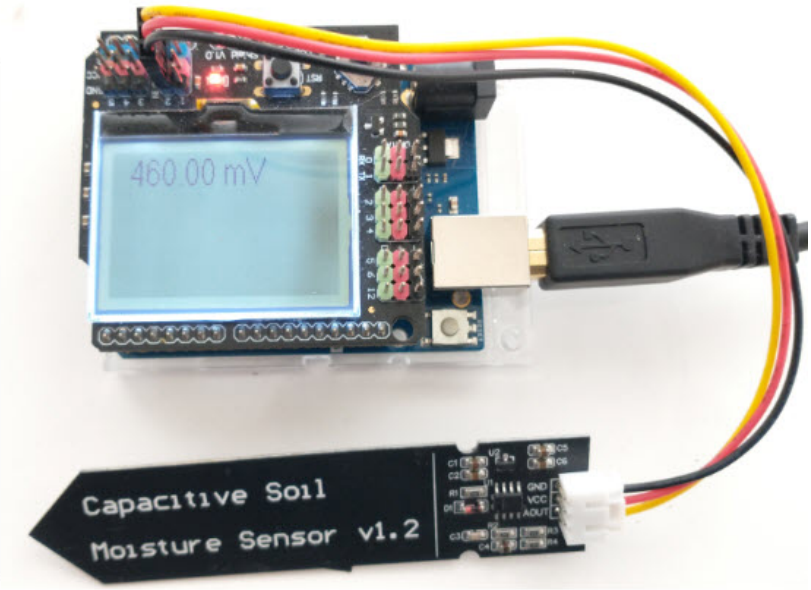
dose at around 2ppm and take note of the effects. From there, you will be able to gauge whether you want to have a higher or lower concentration of kinetin. If the dose is too high, you will start to see some negative effects. Also, time your applications so that they are in line with the effects you want to achieve. If you want to feed kinetin through the roots, use an even lower concentration and make sure your applications are properly timed, avoid having permanent exposure of roots to kinetin, as this is likely to be negative.

Have you ever used kinetin in your crops? What concentrations have you used and what effects have you seen? Let us know in the comments below!

Arduino hydroponics, how to build a sensor station with an online dashboard

In a previous post about Arduino hydroponics, I talked about some of the simplest projects you could build with Arduinos. We also talked about how you could steadily advance towards more complex projects, if you started with the right boards and shields. In this post, I am going to show you how to build a simple sensor station that measures media moisture and is also connected to a free dashboard platform (flespi). The Arduino will take and display readings from the sensor and transmit them over the internet, where we will be able to monitor them using a custom-made dashboard. **This project requires no proto-boards or soldering skills.**





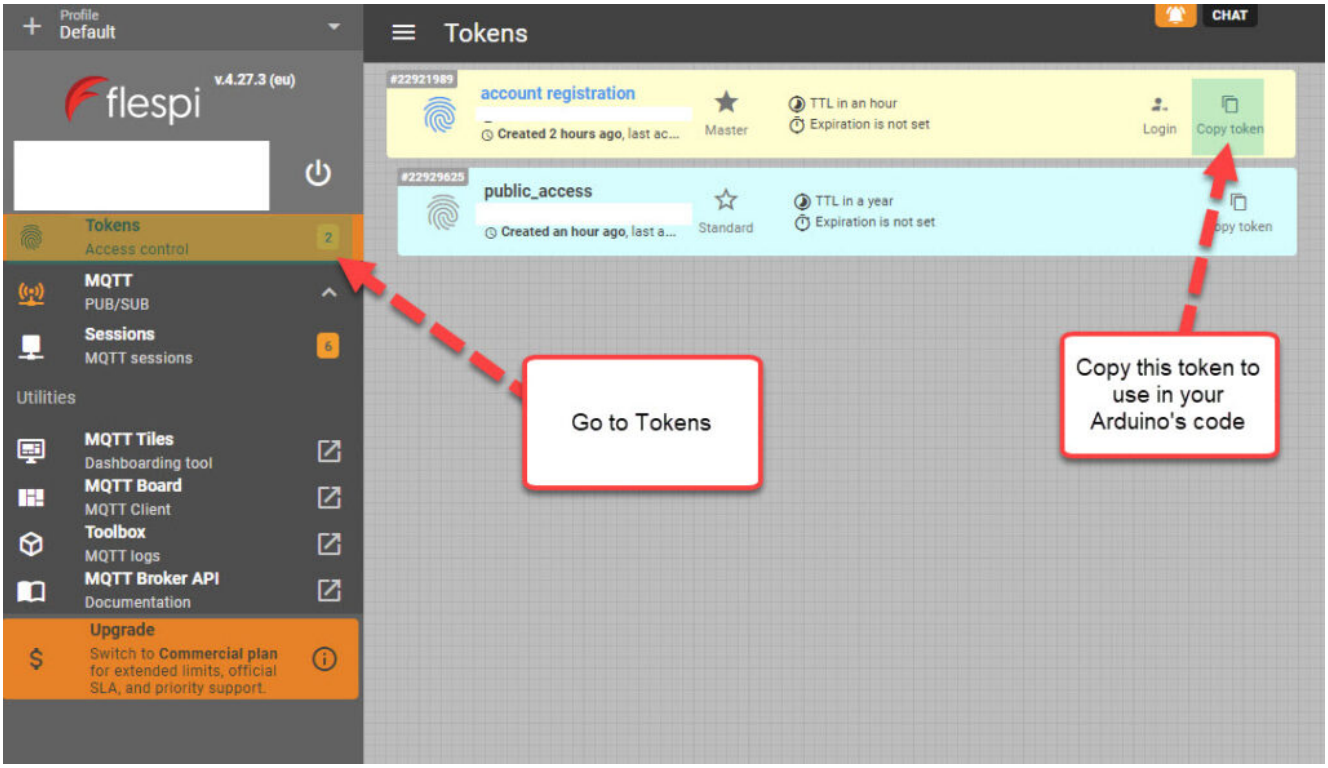
An Arduino Wifi Rev2 connected to a moisture sensor, transmitting readings to an MQTT server hosted by flespi that generates an online dashboard

The idea of this project is to provide you with a simple start to the world of Arduino hydroponics and IoT interfacing. Although the project is quite simple, you can use it as a base to build on. You can add more sensors, improve the display, create more complicated dashboards, etc.

What you will need

For this build, we are going to use an Arduino Wifi Rev2 and an LCD shield from DFRobot. For our sensor, we are going to be using these low-cost capacitive moisture sensors. This sample project uses only one sensor, but you can connect up to five sensors to the LCD shield. Since this project is going to be connected to the internet, it requires access to an internet-connected WiFi network.

Additionally, you will also need a free flespi account. Go to the flespi page and create an account before you continue with the project. You should select the MQTT option when creating your account since the project uses the MQTT protocol for transmission. After logging into your account, copy the token shown on the “Tokens” page, as you will need it to set up the code.



Copy the token from the “Tokens” menu in flespi

Libraries and code

This project uses the U8g2, ArduinoMQTTClient and WiFiNINA libraries. You should install them before attempting to run the code. The code below is all you need for the project. Make sure you edit the code to input your WiFi SSID, password, and Flespi token, before uploading it to your Arduino. This also assumes you will connect the moisture sensor to the analogue 2 port of your Arduino. You should change the ANALOG_PORT variable to point to the correct port if needed.

```
#include <Arduino.h>
#include <U8g2lib.h>
#include <WiFiNINA.h>
#include <ArduinoMqttClient.h>
#include <SPI.h>

#define SECRET_SSID "enter your wifi ssid here"
#define SECRET_PASS "enter your password here"
#define FLESPI_TOKEN "enter your flespi token here"
#define ANALOG_PORT  A2
```

```
#define MQTT_BROKER    "mqtt.flespi.io"
#define MQTT_PORT      1883

U8G2_ST7565_NHD_C12864_F_4W_SW_SPI u8g2(U8G2_R0, /* clock=*/
13, /* data=*/ 11, /* cs=*/ 10, /* dc=*/ 9, /* reset=*/ 8);
float capacitance;
WiFiClient wifiClient;
MqttClient mqttClient(wifiClient);

// checks connection to wifi network and flespi MQTT server
void check_connection()
{
  if (!mqttClient.connected()) {
    WiFi.end();
    WiFi.begin(SECRET_SSID, SECRET_PASS);
    delay(10000);
    mqttClient.setUsernamePassword(FLESPI_TOKEN, "");
    if (!mqttClient.connect(MQTT_BROKER, MQTT_PORT)) {
      Serial.print("MQTT connection failed! Error code = ");
      Serial.println(mqttClient.connectError());
      delay(100);
    }
  }
}

void setup() {
  pinMode(LED_BUILTIN, OUTPUT);
  pinMode(4, OUTPUT);
  Serial.begin(9600);
  analogReference(DEFAULT);
  check_connection();
}

void loop() {

  String moisture_string;
  check_connection();

  // read moisture sensor, since this is a wifiRev2 we need to
set the reference to VDD
  analogReference(VDD);
```

```
  capacitance = analogRead(ANALOG_PORT);
  // form the string we will display on the Arduino LCD screen
  moisture_string = String(capacitance) + " mV";
  Serial.println(moisture_string);
  // send moisture sensor reading to flespi
  mqttClient.beginMessage("MOISTURE1");
  mqttClient.print(capacitance);
  mqttClient.endMessage();

  // the LCD screen only works if I reinitialize it on every
loop
   // I also need to reset the analogReference for it to
properly work
  analogReference(DEFAULT);
  u8g2.begin();
  u8g2.setFont(u8g2_font_crox3h_tf);
  u8g2.clearBuffer();          // clear the internal memory
   u8g2.drawStr(10,15,moisture_string.c_str());   // write
something to the internal memory
  u8g2.sendBuffer();          // transfer internal memory to
the display

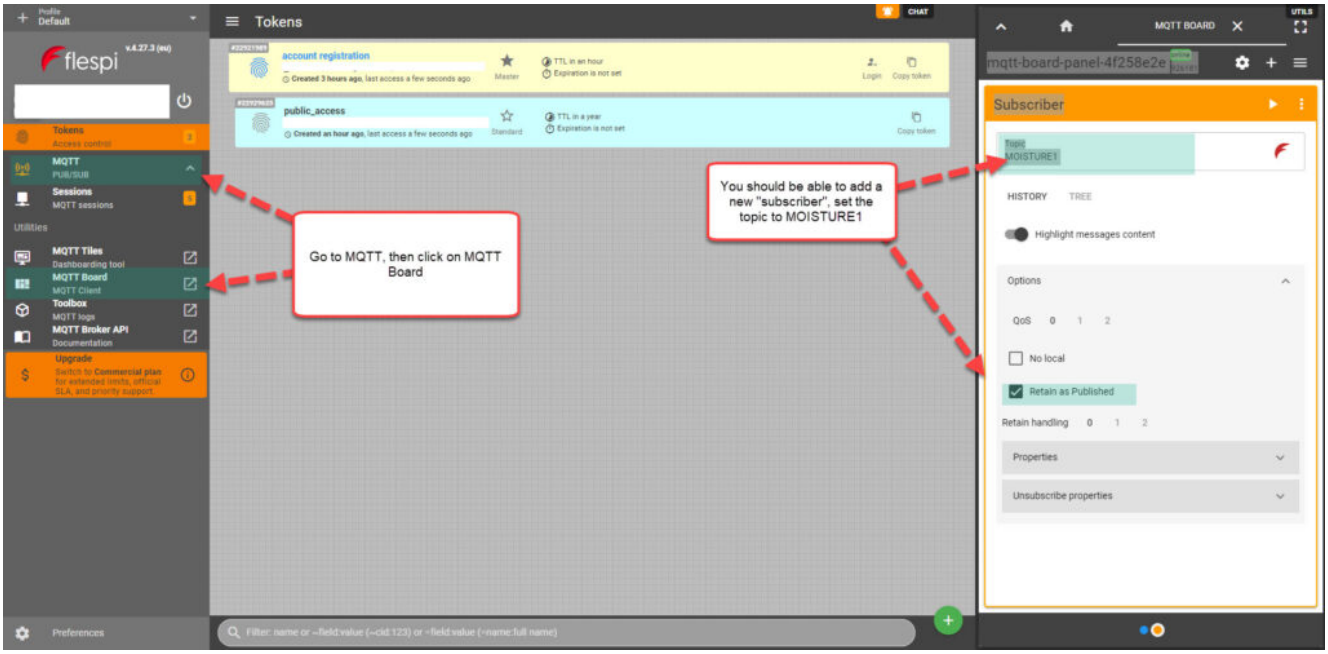
  delay(5000);
}
```

Your Arduino should now connect to the internet, take a reading from the moisture sensor, display it on the LCD shield and send it to flespi for recording. Note that the display of the data on the LCD shield is quite rudimentary. This is because I didn’t optimize the font or play too much with the interface. However, this code should provide you with a good template if you want to refine the display.

Configure Flespi

The next step is to configure flespi to record and display our readings. First, click the MQTT option to the left and then go into the “MQTT Board” (click the button, no the arrow that opens up a new page). Here, you will be able to add a new subscriber. A “subscriber” is an instance that listens to MQTT

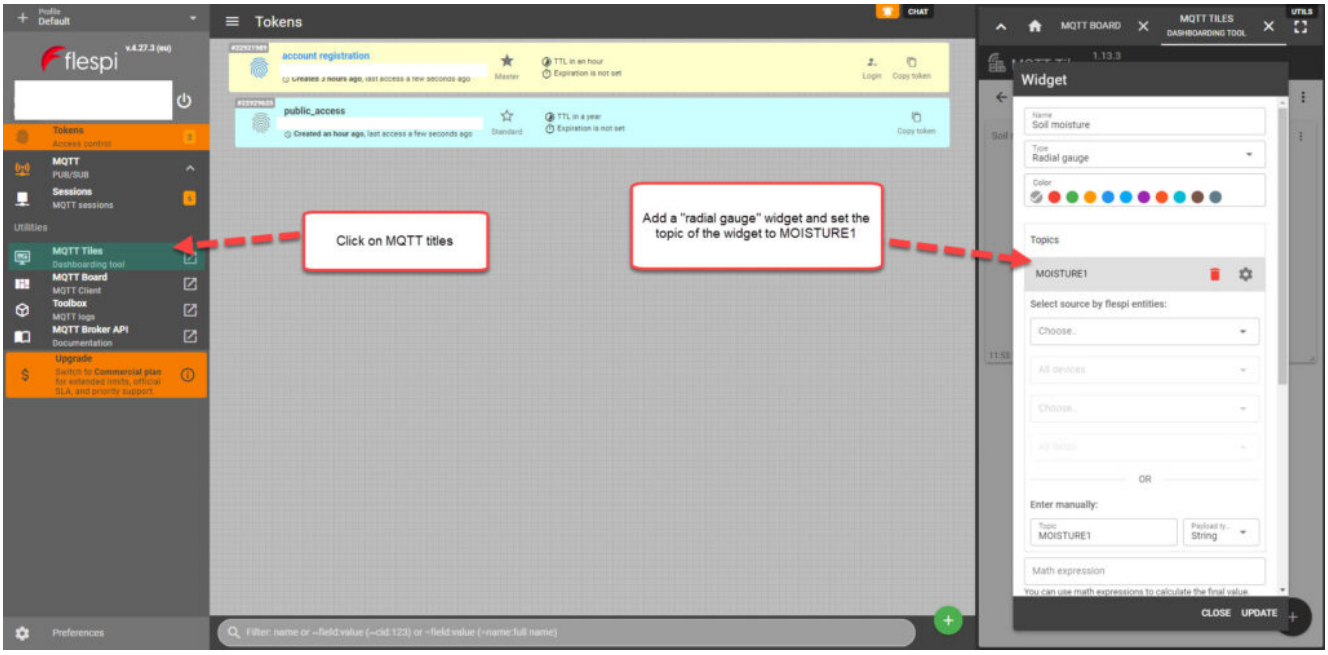
messages being published and “MOISTURE1” is the topic that our Arduino will be publishing messages to. If you want to publish data for multiple sensors, you should give each sensor its own topic, then add one flespi subscriber for each sensor.



Go to flespi and create a new “subscriber”, set the topic to MOISTURE1

Create the Dashboard

The last step, is to use the “MQTT Titles” menu to create a dashboard. I added a gauge widget to a new dashboard, and then set the topic of it to MOISTURE1, so that its data is updated with our MQTT messages. I set the minimum value to 200; the maximum value to 460; and the low, mid, and high levels to 250, 325, and 400 respectively.



Use the MQTT titles menu to add widgets to a new dashboard

After you finish creating the dashboard, you can then use the “Get link” button, which looks like a link from a chain next to your dashboard’s title. You will need to create an additional token in the “Tokens” menu so that you can use it for the sharing of the dashboard. After you generate the link, it should be publicly available for anyone who is interested. This is the link to the dashboard I created.

Conclusion

You can create a simple and expandable sensor station using an Arduino Wifi Rev2, a capacitive moisture sensor, and an LCD shield. This station can be connected to the internet via Wifi and send its data to flespi, which allows us to create free online dashboards. You can expand on this sensor station by adding more moisture sensors or any other Gravity shield compatible sensors, such as a BME280 sensor for temperature, humidity, and atmospheric pressure readings.

How to choose the best hydroponic bucket system for you

You can use simple buckets to create versatile hydroponic systems. You can create a system to grow a few plants at home or thousands of plants in a commercial facility. However, there are several types of bucket systems to choose from, and making the correct choice is vital to success. In this post, we are going to take a look at the different types of bucket systems. We will examine their pros and cons so that you can better understand them and choose the hydroponic bucket system that best suits your needs.

The Kratky bucket

The simplest system is the Kratky bucket system. In this setup, you have a bucket with one or several holes on the lid. You put plants in net pots with media and then fill the bucket with a nutrient solution so that it is barely touching the bottom of the media. The media initially draws water through capillary action, while the roots reach the nutrient solution. After that, the roots draw nutrients from the water and an air gap is created between the plant and the water as the crop evaporates water. The roots use this air gap to get the oxygen they need for respiration. For this reason, you don’t need any air pumps.



Kratky system using mason jars. I would advice to avoid transparent containers to reduce algae growth.

This completely passive system is easy to build and cheap. You only fill the bucket once with nutrient solution, and you don’t need to check the pH, EC, or other variables through the

crop cycle. However, this system requires careful determination of the bucket's volume, the nutrient solution concentrations, and the crops grown. You can read this post I wrote, for more tips to successfully grow using this bucket system.

However, you cannot easily grow large productive flowering plants in this system. This is because large plants consume too much water and nutrients throughout their life, and will require either a very big volume or complete changing of the nutrient solution at several points. For large flowering plants, it is more convenient to use other types of bucket systems that make solution changes easier. If you would like more information and data regarding the culture of large plants using Kratky hydroponics, please read this post.

The Kratky bucket system is ideal if you need a system with no power consumption, your environmental conditions don't have extremes, and you want to grow leafy greens or other small plants on a small scale. For larger scales, Kratky systems to grow leafy greens on rafts do exist, although large-scale systems do involve pumps, at least to change solution between crop cycles.

The bucket with and air pump

The Kratky system has zero power consumption, but does require the grower to carefully manage the initial nutrient level and is not very tolerant to strong variations in environmental conditions. For this reason, a more robust method to grow is the bucket with an air stone. This is exactly the same as a Kratky system, except that air is constantly pumped into the nutrient solution and the nutrients are generally maintained at a specific level inside the bucket.

Constantly pumping air into the solution creates several advantages. The first is that air oxygenates the solution, which means the solution's level is not critical. This is

because plant roots have access to oxygen, even if more than the ideal percentage of the root mass is submerged in the solution. The second is that air will help regulate the temperature of the nutrient solution. As air bubbles through and evaporates water, it helps keep the solution cool. Kratky systems can suffer from unwanted temperature spikes if the air temperature gets too hot. This is a common reason for disease and failure in Kratky systems.



A typical air-pump bucket system growing kit

Systems with an air pump are usually easier for people who are just starting. The low cost and low failure rates are the main reason why this is a very popular choice for first-time hydroponic enthusiasts. However, since water evaporates more, there is a need to at least replenish water through the crop cycle. You are also limited to smaller plants unless you're willing to fully change the nutrient solution several times

per crop cycle, which is inconvenient with a bucket system like this. It is also uncommon to see systems like this on a larger scale, as changing and cleaning hundreds of buckets manually and having hundreds of airlines going into buckets is not practical.

Note that air pumps bring substantial amounts of algae into solutions that will thrive if any light can get into your buckets. For hydroponic systems that use air pumps, make sure you use buckets made of black plastic so that no light gets in. White plastic will allow too much light to get in and algae will proliferate.

You can buy several ready-made hydroponic systems of this type. For example this one or this one for multiple small plants.

The Dutch bucket system

A Dutch bucket system is great to grow large plants. In this setup, buckets are connected to drain lines at the bottom. This allows you to pump the nutrient solution into the buckets and allow it to drain several times per day. The constant cycling of solution exposes roots to large amounts of oxygen between irrigation cycles, making this a great setup for highly productive crops.

The Dutch bucket system is therefore an active system, requiring water pumps to keep the plants alive. This dramatically increases the energy consumption needs of the crop and makes the pumps and timers fundamental components of the hydroponic system. An active bucket system like this will usually give the grower 12-24 hours, depending on conditions, to fix critical components in case of failure before plants start to suffer irreversible damage. To prevent damage in commercial operations, drains will usually allow for some amount of water to remain at the bottom of the buckets so that large plants have a buffer to survive more prolonged technical

issues.



A commercial Dutch bucket hydroponic system

The need to support the plants without water also means you need to use a lot more media, as the bucket themselves need to be filled with it. Since multiple flood and drain cycles are desirable this also means that the media needs to dry back relatively quickly, reason why media like rice husks, perlite or expanded clay, are used. Media costs of Dutch bucket systems are significantly larger than those of other systems because of this. You can run Dutch bucket systems with netpots as well, but this tends to make the system much less robust to pump failure.

Dutch bucket systems are a good choice if you want to grow highly productive large plants. They offer more robustness when compared with NFT systems – which have more critical points of failure – and the large amount of media provides a good temperature buffer and a great anchoring point for large plants. Several small-scale kits to grow using Dutch buckets also exist (see this one for example). However, they take significantly more space than the alternatives we described before. They require access to power and space for pumps, a large nutrient reservoir, and the supporting infrastructure

for the plants. They also require nutrient solution management skills.

Conclusion

Bucket systems are very popular in hydroponics. They can be as simple as a bucket with a hole and a net pot or as complex as Dutch bucket systems with interconnected drain systems and full nutrient solution recirculation.

The easiest system to start with is a hydroponic bucket system with an air pump, as this eliminates the need to gauge the container volume and nutrient level precisely and allows for healthier growth, fewer disease issues, and easier temperature control.

A Kratky system can be great to grow small plants at a low cost with no power, but some experimentation with the nutrient level and concentration is usually required to get a satisfactory crop.

For large plants, the Dutch bucket system is a great choice, if you have the space and power availability. Dutch bucket kits for small-scale growers are also readily available.

Have you ever grown using buckets? Which type of system have you used and why? Let us know in the comments below!

Arduino hydroponics, how to go from simple to complex

Hydroponic systems offer a great opportunity for DIY electronics. In these systems, you can monitor many variables,

gather a lot of data, and build automated control systems using this information. However, the more advanced projects can be very overwhelming for people new to Arduinos and the simpler projects can be very limiting and hard to expand on if you don’t make the right decisions from the start. In this post, I’m going to talk about the easiest way to start in Arduino hydroponics, which materials and boards to buy, and how to take this initial setup to a more complex approach with time.



The Arduino Wifi Rev2

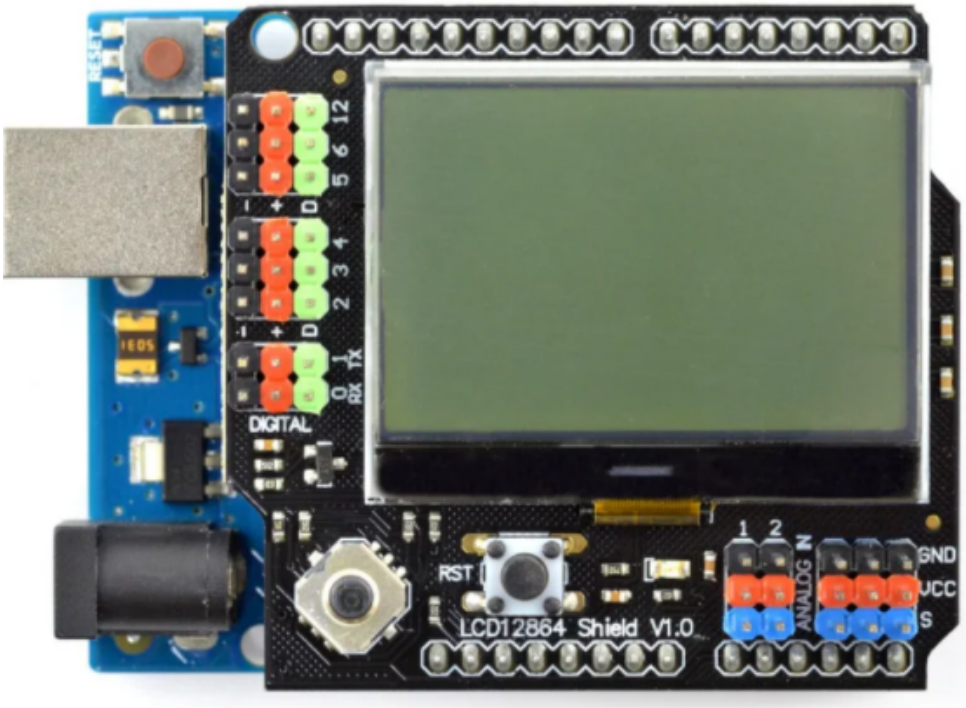
Buy the right Arduino

First, buy an Arduino that allows you to build simple projects without compromising your ability to upgrade in the future. My recommendation would be an Arduino Wifi Rev2. These are small boards that are compatible with Arduino Uno shields, with the ability to connect to your network when you’re ready for more complex projects. Shields are boards that can be stacked on top of your Arduino, which allow you to get additional functionality or simplify the usage of the board. The Arduino Wifi Rev2 is a perfect choice, as you can outgrow simpler boards quickly while the more complicated ones are likely to

be overkill and limit your potential shield choices.

Avoid soldering and protoboards, go for plug-and-play

For people new to Arduino, it is easier to avoid sensors that require soldering or protoboards and go with plug-and-play approaches. My all-time favorite is the “Gravity” system created by DFrobot, which uses shields that expose quick access connectors that you can use to plug-in sensors. My recommendation is the LCD12864 Shield, which has an LED and allows you to connect both analog and digital sensors. If you buy any “Gravity-compatible” sensor, you will only need to hook up a connector, no soldering or protoboards involved. You also have a graphic interface you can program and buttons you can use to interact with your Arduino and code.



The LCD12864 Gravity shield that exposes easy plug-and-play ports for sensors

Start with a temperature/humidity display station

A good beginner project is to create a monitoring station that displays the readings from sensors on a screen. I've written about how to build such a station in a previous blog post. However, since pH and EC sensors can be more complicated, it is easier to start with temperature/humidity sensors only. There are several cheap sensors of this kind, such as the DHT11 and DHT22 sensors, but these have important issues. A better choice for hydroponics is the SHT1x sensor. If you are more advanced, the BME280 sensors are now my low-cost sensor of choice. There are lots of gravity sensors to choose from. You can also monitor CO_2, light intensity, solution temperature, EC, pH, and other variables as you become more advanced.



The SHT1x Gravity sensor, this can be easily plugged into the LCD12864 shield shown before

When you go into EC/pH monitoring, make sure you buy sensors that have electrically isolated boards. The ones from DFRobot are not electrically isolated and have important issues when multiple probes are put in the same solution. Most cheap ones on eBay/Amazon, have the same issues. I would recommend the sensors boards from uFire, which have a lower cost, are properly isolated, and are easy to use. The hydroponic kit collection, offers all the sensors and boards you require, in rugged industrial quality configurations, to build a hydroponic monitoring station.

Next step, simple control

The next step in complexity is control. You can use a Gravity relay to switch a light or timer on or off. You can also use a simple dead-band algorithm to attempt to control your

temperature and humidity values by using relays to turn humidifiers, dehumidifiers, or AC systems on or off. If you want to control nutrients and pH, this is also where you would get shields to run stepper motors and the peristaltic pumps required to feed solutions into a tank. I've used this shield stacked under an LCD12864 for this purpose.

As an example of simple control, imagine your humidity is getting too high, so you install a dehumidifier to keep your humidity from climbing above 80%, you then create a line of code that sets the relay to "on" whenever the humidity gets higher than 80% and shuts it down whenever it drops below 75%. That way your crop's humidity increases to 80%, the dehumidifier kicks in, and then it shuts down when it reaches 75%. This allows the setup to climb back up for some time, avoiding the continuous triggering of your appliance.

Data Logging

After you're comfortable with both monitoring setups and simple control, the next step is data logging. Up to this point, none of your setups have done any data logging. By its very nature, an Arduino is not built to log any data, so this will require interactions with computers. My favorite way to do this is to set up a MyCodo server on a Raspberry Pi, then transmit data to it using the MQTT protocol. Since your Arduino Wifi v2 can connect to your Wifi network, you will be able to transmit data to your MyCodo using this configuration.



A sample of the data-logging capabilities of a MyCodo server. Taken from the [MyCodo site](#).

I have previously written posts about [MyCodo](#), as well as [how to build a pH/EC wireless sensing station](#) that transmits data to a MyCodo server. This allows me to log data continuously and monitor it without having to go into my hydroponic crop. Since the server is centralized, it also allows you to monitor multiple sensing stations simultaneously. I use my MyCodo server to monitor both my hydroponic crops and Arduino sensing stations that monitor how much food my cats eat.

More complex control

After you have connected your Arduino to a MyCodo server, you have access to much more complicated control, through the Raspberry Pi computer. You can then implement control

algorithms in the MyCodo, then communicate with your Arduino, and trigger actions using MQTT messages. This means that you no longer need to code the control logic into your Arduino but you can do all the control in the raspberry Pi and just communicate the decisions made to the Arduino Wifi Rev2.

More complicated algorithms includes the use of proper PID algorithms for the control of humidity, temperature, pH and EC. It also includes the implementation of reinforcement learning algorithms and other advanced control methods that the Raspberry Pi can have the capacity to run.

Conclusion

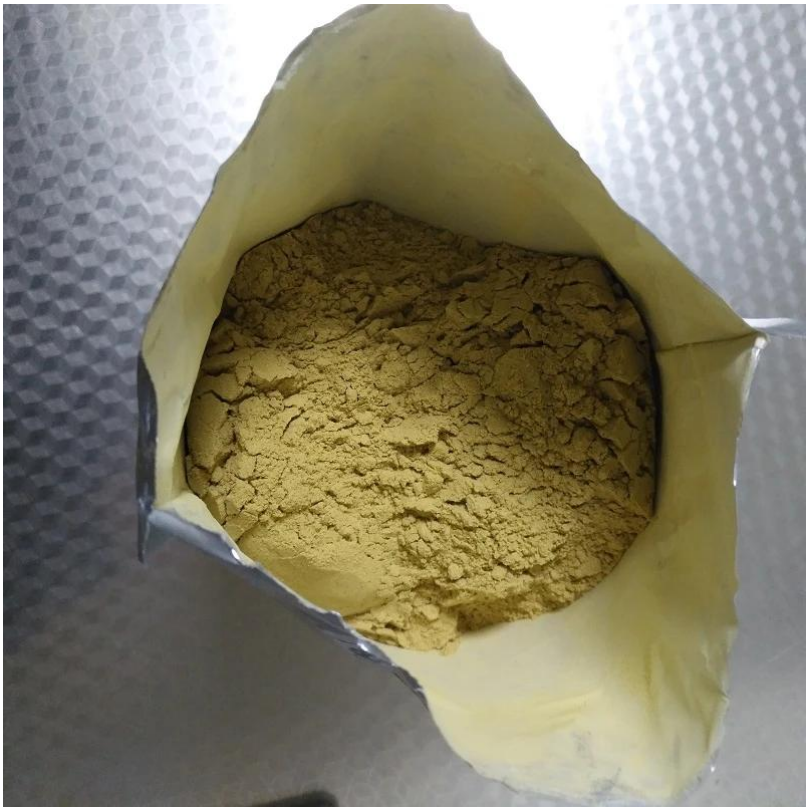
Arduino in hydroponics does not need to be complex. Your first project can be a simple temperature/humidity monitoring setup and you can evolve to more complicated projects as your understanding and proficiency grow. If you select a powerful and feature-rich Arduino from the start, you can use the same controller through all your different projects. If you select shields that can make your life easier – such as the LCD12864 shield – and use a plug-and-play sensor interface, you can concentrate on building your setup and your code, rather than on soldering, getting connections right, and dealing with messy protoboard setups.

The road from a simple monitoring station to a fully fledged automated hydroponic setup is a long one, but you can walk it in small steps.

Have you used Arduinos in your hydroponic setup? Let us know about your experience in the comments below!

A great trick to higher chelate stability in hydroponics

The stability of micronutrients in hydroponic solution has been studied in depth during the last 5 decades (1). The EDTA molecule was the first cheap synthetic ligand that created highly stable chelates that could be used to stabilize heavy metals in solution. After this, efforts to create more stable chelates continued, with the introduction of HEDTA, DTPA, EDDHA, and other synthetic ligands. However, the stability of iron in solution still remains a problem. This is due to the chemistry of heavy metals in solution and the issues that arise as root zone chemical conditions change in a hydroponic crop. In this post we will discuss a simple trick, to increase the stability of the cheaply available iron EDTA chelate, the most commonly used in nutrient solutions. **Note, the term "heavy metal" in this post is used to refer to the transition metals used in hydroponics, mainly Fe, Zn, Mn and Cu.**



$Na_2FeEDTA$, one of the most commonly used Fe chelates in hydroponics.

Chelate stability

The stability of chelates is dominated by three competing forces. The first is the acid/base equilibrium of the ligand. Ligands like EDTA are only able to chelate Fe when their active sites are not occupied by hydrogen ions. As the pH goes down, these sites become occupied and the $EDTA^{-4}$ turns into $HEDTA^{-3}$, then H_2EDTA^{-2}, H_3EDTA^{-1}, and finally H_4EDTA. This process frees the heavy metal ions as the concentration of the active ligand ($EDTA^{-4}$) drops to near zero values. At very acidic pH values, the Fe^{2+} will effectively become fully unchelated due to this effect, although this does not happen to a very large extent at the pH values we see in hydroponics.

The second effect has to do with the affinity of the ligand for the heavy metal. This is what we call the “stability” of the chelate. It is measured through the use of the equilibrium

constant of the reaction of the metal with the ligand. The larger this value, the bigger the stability of the chelate will be and the less free metal we will have in solution. For more information about this, you can read this previous post, where I share a table with a lot of stability constants for different ligands and heavy metals.

The third is the precipitation of free heavy metal ions by the formation of insoluble solids. This can be quite critical, as several of the solids that can form in hydroponics, mainly hydroxides, and phosphates, have very low solubility values. These can be compared by using the equilibrium constant of the solid with the ions in solution, what we call the Ksp in chemistry. The smaller the Ksp, the more insoluble a substance is. When these solids precipitate they take ions away from the solution and these are regenerated by the chelated heavy metal equilibrium reaction. This depletes the heavy metal slowly from the solution.

Free heavy metal ions

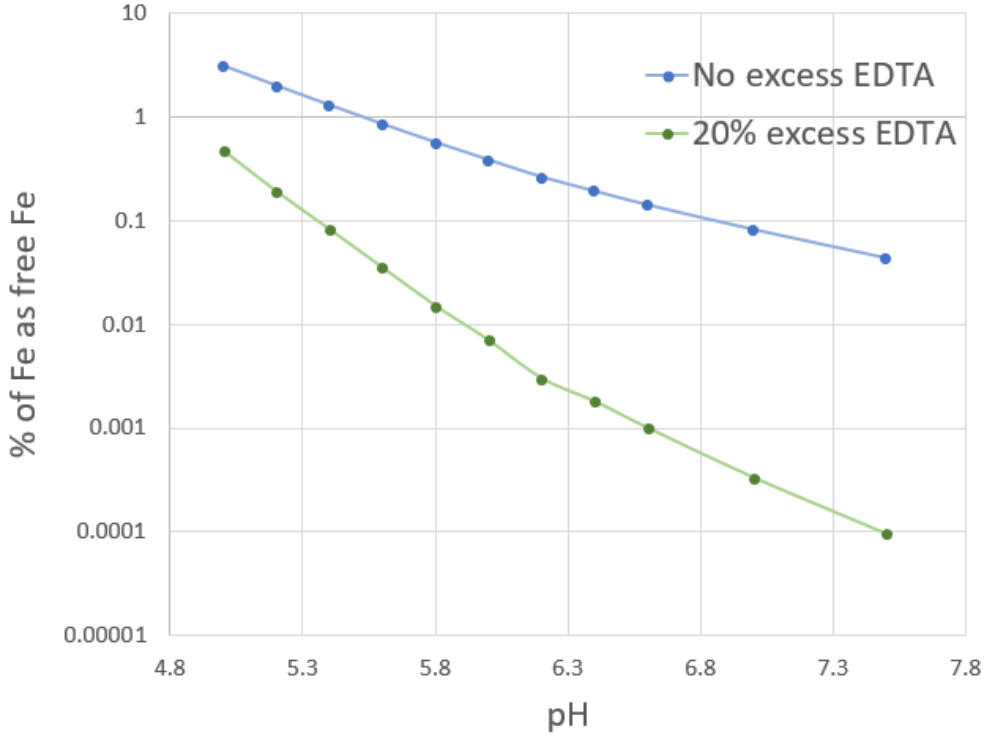
Since free heavy metal ions are the ones that can precipitate and become unavailable, what we desire is to lower the amount of free heavy metal ions in solution and increase the percent of chelated ions. Whenever you put a chelated heavy metal source in solution, like $Na_2FeEDTA$, the chelate goes into equilibrium with its unchelated form and all the acid/base species of the ligand's equilibrium reactions. This means that a percentage of the Fe becomes effectively unchelated. **In a solution where 1ppm of Fe from $Na_2FeEDTA$ is added, P is added at 30ppm and the pH is set to 6, around 0.38% of the Fe will be unchelated**.

As the pH increases the amount of free Fe actually decreases – as the acid/base equilibrium of the ligand shifts towards the base forms – but the concentration of other ions that can precipitate really insoluble salts, like phosphate or

hydroxide, increases dramatically. At pH values above 7, even a small fraction of free Fe can lead to precipitation of some Fe salts. This is why iron EDTA chelates are not considered to be stable in basic pH, not because the chelate itself is unstable, but because there are even more stable Fe solids that can form and precipitate out the Fe.

A simple trick to alleviate the issue

Traditionally, the issue of having unchelated heavy metals has been approached by creating stronger chelates. DTPA, which has much higher stability constants, is able to generate much lower amounts of Fe, which leads to lower precipitation. The equilibrium constant with some isomers of EDDHA is actually so high, that no Fe solids are formed across almost the entire pH window in water. However, these chelates are more expensive, and – in the case of EDDHA – the presence of several different isomers complicates the situation.



Solution always has 1ppm of Fe added as $Na_2FeEDTA$ with 30ppm of P. The above was calculated using a system of equations

accounting for all the EDTA and phosphate acid/base equilibria, as well as the heavy metal chelation.

A very simple trick to partially solve the problem is to add an excess of chelating agent into the hydroponic solution. If you're using EDTA, adding Na_2H_2EDTA on top of the heavy metal chelates can greatly help reduce the amount of free heavy metal in solution. This EDTA will also not remain unbound, as it will quickly chelate Mg and Ca in solution. These Ca and Mg chelates, will act as a reserve of ligand to ensure that almost all heavy metal ions are chelated. A 20% molar excess can generate dramatic results in the case of Fe^{2+}, as shown in the image above. This 20% "reserve" ligand, reduces the amount of free Fe by a factor of 10-100x, depending on the pH. Note that although the above slows down any precipitation reactions – as little free Fe is available – the hydroxide and phosphate ions will still win if the pH increases enough, as the stability constant of the Fe EDTA reaction remains the same.

To give a 20% excess of EDTA in molar terms, add 1.2mg/L of disodium EDTA to the final nutrient solution for every 1ppm of Fe. You can also add a 100% molar excess with no ill effects on plants, which will provide a more pronounced effect.

Conclusion

Adding a chelated heavy metal form to a hydroponic solution does not ensure that the metal will always be chelated. The chemical equilibria that exist with the free form of the heavy metal always happen and will always generate some percentage of free, unchelated metal. By adding an excess of the chelating agent, in this case, Na_2H_2EDTA, we can strongly displace the equilibrium and reduce the amount of free heavy metal present. The lower amount of heavy metal increases the pH stability window of the chelate and reduces the precipitation issues that happen as a consequence of free heavy metal ions being present in solution.

Do you add excess chelating agent to your nutrient solutions? Let us know about your experience in the comments!

Hydroponics vs soil, all you wanted to know

Hydroponics seeks to grow plants without soil. But is this any better? In this post, we are going to take a deep dive into the peer-reviewed literature comparing soil crops with hydroponic ones. We are going to look at papers that compare yields, quality, cost, and environmental impact. This will help us determine which growing method is better and under which circumstances. In this comparison, “hydroponics” encompasses any crop grown without soil, including those grown in soilless media.



Lettuce grown in a hydroponic and soil setup

How to compare

It can be hard to compare soilless and soil culture due to the many ways in which both can be done. Soil crops can be grown with or without fertilization, with or without irrigation restrictions, organically or with synthetic fertilizers, in a greenhouse or the field, etc. Different soils can also have widely different qualities and properties. Similarly, hydroponic crops use a wide variety of different systems and nutrient solutions. For this reason, I will focus my analysis on publications that try to directly compare products grown under both methods by the same researchers.

I will also look into literature reviews that try to describe the global picture. These articles can be important, as they can help us evaluate the impact of soil and soilless culture on a much larger scale. These can help us see the impact of all the different methods used and how tilting the scale one way might affect the big picture.

Quality

Many different studies have compared the quality of vegetables and fruits grown in hydroponic and soil cultures. The table below, shows you some of these studies and my assessment of the "winner" in each one, given their conclusions. I also analyzed these reviews on the matter (12, 13) that looked at the publications on the subject.

Ref	Product	Property	Winner
1	Lamb Lettuce	Shelf-life	soil
1	Lamb Lettuce	Quality	soil
2	Strawberry	Size	hydro
3	Lettuce	Nutrient density	hydro
4	Soybean	Nutrient density	hydro

5	Strawberry	Nutrient density	hydro
6	Strawberry	Nutrient density	hydro
6	Raspberry	Nutrient density	soil
7	Strawberry	Nutrient density & taste	hydro
7	Raspberry	Nutrient density & taste	hydro
8	Strawberry	Nutrient density	soil
9	Strawberry	Quality	soil
10	Cucumber	Quality	hydro
11	Pepper	Antioxidants	hydro
12	Pumpkin	Quality	hydro

Different studies comparing soil and hydroponic crops

The above results show us that, while hydroponics can produce better or equal results compared with soil, it is by no means guaranteed to do so. If the conditions of the hydroponic system are not adequately controlled or the soil is of much higher quality, the hydroponic system might perform worse.

Neither soil nor hydroponic systems are a guarantee of better or worse quality. It is false to assert that soil crops – even those grown organically, as in some of the above studies – can always provide better results compared to a hydroponic crop. Nutrient density, freshness, taste, and quality can be just as good or even better in a hydroponic system.

However, because of the larger control that the grower exerts in a hydroponic system, it is probably easier, on average, for an inexperienced grower to deliver better results in soil. This is because soil culture is more forgiving, and takes care of more aspects that a grower would have to directly control in a hydroponic system, such as root zone chemical conditions.

Yield

I would suggest reading this blog post I wrote about hydroponic yields first. In it, I talk about the issue of

yield in hydroponics, and how the most frequently cited yields per acre – which come from a couple of books that do not properly cite their sources – cannot be assumed to be reliable. To compare with soil, we should therefore look at publications that have done their own experiments to compare both types of culture.

Yield, mean weight and number of total (T), marketable (M) and unmarketable (NM) fruits of zucchini plants grown on four substrates Values are the means of four replicate samples. In each column, values followed, by the same letter do not differ significantly at P = *0 05*

	Yield (g/plant)			Fruit (g/fruit)			Fruit (No./plant)		
Substrate	T	M	NM	T	M	NM	T	M	NM
Cocofibre	2343^{a}	2291^{a}	55^{b}	109.3^{a}	113.9^{a}	41.6^{a}	21.3^{a}	20.1^{a}	1.2^{c}
Perlite	2105^{ab}	2030^{a}	69^{ab}	110.3^{a}	115.7^{a}	28.0^{b}	19.8^{a}	17.3^{a}	2.5^{ab}
Pumice	2178^{ab}	2134^{a}	51^{b}	112.9^{a}	118.9^{a}	35 7^{b}	19.3^{a}	17.9^{a}	1.4^{bc}
Soil	1762^{b}	1640^{b}	123^{a}	100.0^{a}	116.3^{a}	34.2^{b}	17.6^{a}	14.1^{b}	3.5^{a}

Yield comparison for zucchini grown under a variety of different soilless media and soil. Taken from here.

From the articles I reviewed on the subject, none of them gave soil the upper hand. All articles showed an increase in yield in terms of product produced per plant or area, to hydroponic growing (14, 15, 16, 17, 18). However, it was notably difficult to find articles comparing soil and soilless growing methods directly in terms of yield (as you can see I only found 5). This is likely because it is widely assumed that hydroponic crops always give larger yields per acre, so few bother to study this difference directly.

The magnitude of the yield differences is also interesting. Although the books described in my post about "hydroponic yields" cite differences greater than two orders of magnitude, the studies show differences that are always lower than one order of magnitude and most of the time below a 2x increase in yields. This means that, while hydroponic crops are more productive per area, to expect yield increases of 10x when going from soil to soilless culture is unreasonable. Depending on the crop, increases of only 20-30% might be reasonable.

It is also important to understand that higher yields are associated with more complicated hydroponic setups. For this reason, the largest reported yield increases might only be

accessible through much larger capital investments.

Environmental impact

The environmental impact of hydroponic crops depends largely on how they handle nutrient solutions (18, 25). Open hydroponic systems will have significantly more water and fertilizer usage than closed systems. In closed systems, the type of system and the efforts made to treat and reuse nutrient solutions will play a key role in determining environmental impact (19, 20). With this in mind, an open hydroponic system is highly undesirable in terms of environmental impact. However, if you treat the runoff (22), this would be desirable over a soil system that uses synthetic fertilizers.

Note that the environmental impact of hydroponic systems increases dramatically if it uses artificial lights. If this is the case, a soil-based approach will always have a lower impact, unless renewable sources are used to produce the energy.

In the case of soil, environmental impact can be very different depending on the growing practices used. Organic growing approaches will deliver significantly lower impact compared to traditional soil agriculture, mainly due to the lower energy expenditure and because they avoid contamination of soil and aquifers with large amounts of nitrates and phosphates (21).

When considering environmental impact, it is also important to consider yields per area. While a closed hydroponic crop might have a higher environmental impact per acre of land used than an organic soil crop, if it produces 3x more product, the environmental impact per gram of fruit or vegetable produced might be much lower. Although I couldn’t find any direct studies comparing the environmental impact of soil and hydroponic approaches, it would be reasonable to think that a

closed hydroponic system should have a lower environmental impact per gram of product, as long as the yields per area are significantly higher compared to the organic soil approach.

With that said, an approach that makes use of low energy inputs makes very efficient use of water, and has a high planting density, might be the ideal growing system in terms of environmental impact. I suggest you read my blog post about aquaponics if you're interested in this topic. Closed hydroponic systems that use treated sewage instead of newly prepared hydroponic nutrients might also be extremely low-impact, high-productivity systems (22, 26).

Cost

Money is important in agriculture, as it is often the main driver when determining the growing system. Hydroponic crops have higher startup costs compared with soil. This is because the minimal hydroponic setup is substantially more complex relative to the minimal soil setup. However, even when greenhouses are involved, the hydroponic setups will often have higher starting costs (23).

Although starting costs are higher, life cycle costs of hydroponic setups can be lower due to higher yields, fertilizer, and water use efficiency. This is especially the case when you grow highly efficient crops, like lettuce. In this study, (24) they compared the yield, cost, and water efficiency of different hydroponic and protected soil setups. Hydroponic NFT setups were much more water-efficient and much more feasible from an economic perspective.

Hydroponic crops also have access to areas that are traditionally unavailable for soil agriculture. For example, hydroponic crops can be grown on rooftops and produce significantly more money than solar panels under some conditions (25). In this case, hydroponic crops fill a niche that has no soil-based equivalent, since the area would never

be used by soil agriculture.

Conclusion

The best soil grower is better than the worst hydroponic grower. The best hydroponic grower is better than the worst soil grower. The most important thing when you decide to grow a certain way, is to strive to do it in a manner that leads to higher quality, that maximizes yields, minimizes environmental impact and, if possible, is done at a low cost.

Soil agriculture has its place. It is cheaper to start with, requires fewer materials, can be done at a much larger scale, and can produce high-quality, sustainable results when done correctly. Hydroponic culture offers higher yields per area, potentially lower environmental impact, and lower life cycle costs. However, it costs more and requires substantially more knowledge and care to provide comparable results.

Have you grown in soil and hydroponics? Which one do you like best? Let us know in the comments below!