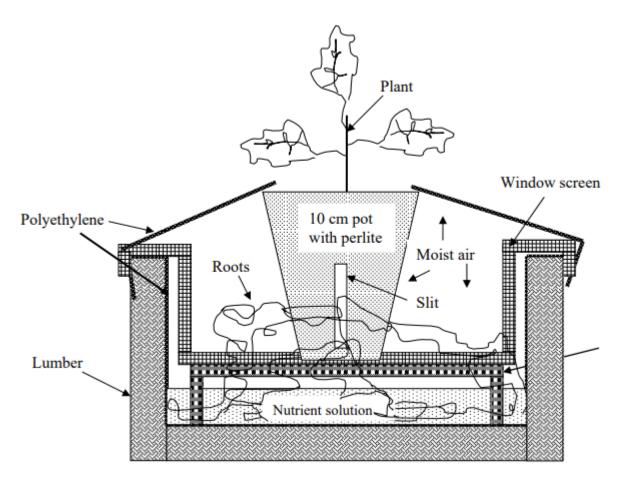
Can you grow large flowering plants like tomatoes using the Kratky method? (passive hydroponics)

I have previously shared some tips on how to grow successfully with the Kratky method in my blog before $(\underline{1})$. This growing system, which was developed in the early 2000s, uses completely passive setups to grow plants, completely eliminating the need for any recirculation and — for smaller plants — even eliminating the need to replenish nutrient solution. However, the traditional set-and-forget methods used to grow small plants, runs into heavy limitations when confronted with the growing of larger flowering plants, like tomatoes. In this post we're going to look into these issues, some of the scientific literature on the matter and some setups that can actually be used for the growing of large flowering plants under commercial growing conditions.

In the Kratky method you place a seedling in a cup with a small amount of media on top of a large container filled with solution up to the point where the solution slightly touched the cup. The plant feeds from the nutrient solution, lowering its level and opening up an "air gap" that the plant's roots can use to get the oxygen they require. Small plants — most prominently lettuce — can be grown like this, because the crop cycle is short enough so that the amount of water in a reasonably size container can last for the entirety of the plant's life. The effect of the plants on the solution is also milder — due to their smaller size — so nutrient imbalances created in the solution by plant absorption and plant exudates are limited.



Taken from the <u>2005 Kratky paper</u> on growing tomatoes passively.

With bigger plants, it's an entirely different deal. A healthy, heavy producing tomato plant will go through 20-30 gallons of water in its entire cycle, so a simple container-based Kratky method would need to have a huge container in order to grow a plant equivalent to a plant grown in traditional hydroponic methods (think a 55 gallon drum). Trying to do this in smaller containers leads to poor results due to the changes that the tomato plant causes in the nutrient solution. Extreme changes in pH — often reaching 9-10 — and great imbalances, will hinder nutrient absorption and lead to quite extreme nutrient deficiencies and problems within the plants. In the best cases the plants will be stunted, limited in production and will yield lower quality produce while in the worst cases they will die and fail to produce any useful harvest.

It is therefore impractical to have a fully passive hydroponic system to grow tomatoes or other large flowering plants —

especially if we want to rival the production potential of other hydroponics methods — but this doesn't mean we cannot try to get close. Kratky published a paper in 2005 that tries to create such a system (see image above). In these systems tomatoes are not grown in containers that are perpetually left alone but they are suspended above beds where the nutrient solution rests. Nutrients are only added once — at the start of the crop — and the solution level is maintained at a desired point using fresh water. Since the volume of solution in these beds is much larger than in single containers, the tomatoes generally do much better. The tomatoes also have access to the solution that is used by many other plants, so imbalances also tend to be smaller than those of single container setups. The beds made of lumber and plastic lining are also cheap to build and provide a potentially viable way to do this commercially, although the non-recirculated solution does provide a nasty breeding ground for mosquitoes, a huge problem for this type of setup at a larger scale.



Image taken from this article.

Can you get commercially viable yields without having a 55

gallon drum per tomato plant? If you're careful! At around the same time Kratky was experimenting with his lumber beds, a group in Pakistan was trying to grow tomatoes in 13L containers using different hydroponic solutions (published here). They initially filled the container with nutrient solution but it is unclear from the paper how the solution was replenished. Since the published volumes of solution used were much higher than the container volumes, it can be assumed that water was added, but it is unclear whether this water contained nutrients or not. Since they say that the pH/EC were observed/adjusted it is reasonable to think that they maintained a certain level within the containers and measured the pH/EC trying to correct these variables with water, nutrients or pH up/down additions with time. They obtained good results with the Cooper solution but the fact that constant monitoring and adjusting was necessary shows that this technique is likely not viable for large scale commercial production as individual monitoring of plants would be a nightmare.

There is a significant lack of research after 2005 in this area, most probably because it has been established that you need to compromise pretty heavily with large flowering plants if you want to grow them without nutrient recirculation or loss of nutrient solution. Systems absolutely need to have very large solution volumes — so large growing beds are probably one of the only viable commercial choices — just because of the water/mineral demand coming from the plants. Additionally the amount of minerals drawn from the water will be large and the imbalances created by their uptake will be large as well. Furthermore, problems with large volumes of stagnant solutions are not small, accumulation of larval pests will be quite substantial and might require the addition of chemical treatments or a lot of additional mesh/netting to alleviate the problem.

If the system is not very large in volume then it becomes

inescapable to deal with the toxicity of the solution, which means to adjust it accordingly. At the very least, measuring pH and EC and adjusting them accordingly is the minimum threshold to achieve results that would be acceptable at a commercial level. It is however not viable to do this at a larger scale, as the plants are heavy and having to open the containers, measure and move the plants is likely to cause damage and be very expensive in terms of labor costs.

If you don't care about volume of production or quality that much and you just want to grow some tomato plants, then doing the Kratky method for tomatoes in 5 gallon containers with a properly formulated hydroponic solution for this purpose might yield some harvest, but the results will be very inferior to those that you could get with either a recirculating system or even a simple drain-to-waste system where the plant is just watered with nutrients with proper monitoring of the EC/pH of the run-off.

Timing irrigations with moisture sensors in hydroponics

After discussing the different types of off-the-shelf sensors for measuring moisture in hydroponics (1,2,3), we are now going to explore the practical use of these sensors to time irrigations within a hydroponic crop. In this post, I'm going to share with you some of the key aspects of timing irrigations using moisture sensors as well as some useful resources I have found in the scientific literature that discuss this problem. We will mostly discuss sensor

calibration, placement, and maintenance.

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Some sample curves of volumetric water content as a function of sensor output. Taken from here.

In principle, the use of sensors to perform irrigations sounds simple. Wait till the sensor tells you there is little water in the media, turn on irrigation, wait till the sensors says there is enough water, turn irrigation off and wait for the process to repeat. However, there are several issues that complicate the problem, which need to properly considered if you want to successfully use these sensors for irrigation. The first such issue is the "set point" of the irrigation — when a sensor triggers an irrigation event — and how we can determine this.

Ideally, the first thing you will do with a sensor is calibrate it for your particular media to ensure that you can equate a given sensor reading with a given moisture content. The procedure below describes how this is can be done:

- 1. Fill a container of known volume with drain holes with fully dry media without any plants.
- 2. Weigh this full container.
- 3. Insert the moisture sensor in it and take measurements till you have a stable reading. This will be the sensor set point.
- 4. Wet the media with nutrient solution until there is substantial run-off coming off the bottom.
- 5. Wait till the run-off stops.
- 6. Weigh the media and take one moisture sensor reading every 1-2 hours, recording the time of each reading, until the media goes back to within 10% of the value of the initial reading.

With this data you can plot a graph of sensor signal vs water content (measured weight — dry weight) that you can use to determine what different signals from the sensor correspond in

terms of amounts of water within the media. You can translate that water weight into volumetric water content by calculating the volume of water from the weight and then diving that by the total volume of the media. You should in the end arrive to curves like the ones shown above, where you can use regression analysis to create a relationship between moisture content and the sensor signal.

With the sensors now calibrated you can now decide on a set point for the irrigation based on how much dry back you desire. The optimal point for this will depend on your VPD and your growing objectives — whether you want to save water, maximize yields, etc — but starting with irrigations at a 50% dry-back point is usually a good idea, if no other guidelines exist. Some plants species are not very sensitive to this point — see this paper on basil — provided that you allow for enough dry-back for adequate oxygenation of the root system. By allowing deeper dry-backs you can save on water, although this can be problematic if your irrigations are done with nutrient solutions of significantly high strength. The ratio of plant size to media volume will also play a role as larger plants in smaller containers will tolerate shallower dry-backs as the total amount of water in the media will be smaller.

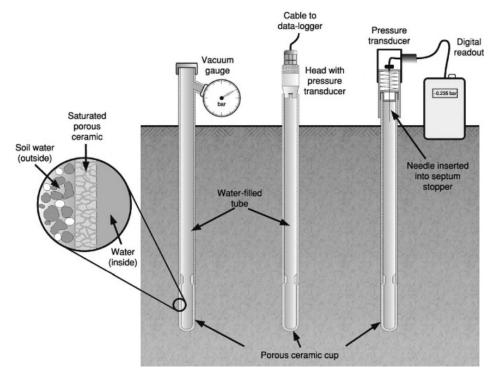
When an irrigation event is triggered it is also worth considering for how long this event will happen. If you water only till the sensor gives you a high moisture content reading, then there will be very little run-off and nutrients will tend to accumulate in the media and imbalances will be created since nutrients that are not absorbed cannot be leached out. For this reason, irrigations are usually continued for several minutes after sensors reach their high moisture reading, in order to ensure that enough run-off is collected to avoid these problems.

Sensor placement is also going to be critical for irrigation timing since you want to ensure that all plants are properly watered. Since irrigation events will generally be triggered by a single sensor, it is up to the grower to decide whether the risk of under or over watering is more acceptable. If the risk of underwatering is considered more important, the sensor will usually be placed in the plant that is largest, has the location with the micro-climate with the highest VPD, and which receives the most light. This is going to be the plant with the highest water demand and most likely the first to need irrigation, if you irrigate whenever this plant needs water, then almost everything else will be at a point of higher moisture content. This can be a dangerous game though, especially if over-watering can be problematic. In these cases, it is usually better to have multiple sensors and irrigation zones and make decisions based on more complex control processes. You can read more about irrigation timing and irrigation in hydroponics in general here.

The last important point here is sensor maintenance. Assuming that moisture sensors will always work in the same way can be a recipe for disaster because these sensors can deteriorate due to a variety of reasons. Since they are exposed to highsalinity, wet environments, contacts can corrode, leads can break and salts can accumulate within sensor structures. For this reason, it is good practice to wash these sensors with distilled water with some frequency — usually I recommend at least once per month — and to recalibrate the sensors at least once per year. It is also good to keep a a couple of already calibrated sensors in reserve, such that these sensors can be deployed quickly if an irrigation sensor fails. To be safer, have irrigations controlled by measurements taken by two sensors in the same plant and be alerted if the measurements of these sensors diverge, this usually indicates that a sensor has deteriorated and needs to be changed.

Tensiometers (irrometers) the best way to time irrigations in hydroponics

I have recently written blog posts about the measurements of water content in media in hydroponics. The <u>first one</u> was about the problems with resistive moisture sensors in hydroponics and the <u>second one</u> showed you a low-cost capacitive sensor that does the job adequately. However, while capacitive sensors are significantly better at measuring moisture compared to resistive sensors, they are not the only type of reliable sensor that we can use to measure water content in hydroponics. In this post, I want to talk about tensiometers and how they can be used to measure water potential in hydroponics and soil. We will go a bit into how tensiometers work and why they are the most reliable sensors for irrigation timing.



Overall layout of modern tensiometers

Both capacitive and resistive sensors try to measure the amount of water in the media by measuring how the electrical

properties of the media change when different amounts of water are present within it. However, plants do not care so much about how these electrical properties change but they care most about the effort that is required to move water from the media into the plant's root system. The tensiometer is a sensor that is designed to measure the difficulty of this process. The device is built using a ceramic cup that is filled with degassed distilled water that a pressure gauge is attached to. When water is not present outside the tensiometer, the water inside of it will face a pressure to go out — causing the pressure gauge in the tensiometer to sense a vacuum — as water is added to the media, this pressure is reduced.

The above is very similar to what plants actually experience. When the media is wet, the plant has an easier time taking water into its root system, when the media is dry, the plant needs to fight in order to keep water inside of its roots from flowing into the media. Since this process mimics what the plants actually care about, it accounts for a lot of variables that can directly affect this pressure, such as the osmotic pressure of the solution and the chemical composition of the media. While resistive sensors are harshly affected by these variables and capacitive sensors are to a large extent insensitive to them, tensiometers account for them in a way more similar to how plants do.

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Digital tensiometer from irrometer.com

Although tensiometers can be analogue — as shown in the first image in this post — there have been great strides in the creation of digital tensiometers that you can use to monitor your crops. The company Netafim (who did not sponsor this post and does not have any affiliation with me) provides digital tensiometers that send measurements to a central hub with data logging capabilities. Although they have been created mostly for soil, they can also be used in hydroponics to directly

monitor the moisture content — or perhaps more accurately the "drying pressure" — of the media. You can also find tensiometers at <u>irrometer.com</u> (who did not sponsor this post and do not have any affiliation with me) where you can get both analogue and digital sensors that you can use within your custom setups, including Arduino builds. In a future post I will show you how to build such a monitoring setup. Please note that the Watermark sensor they sell is *not* a traditional tensiometer, it is a type of resistive sensor that also uses a ceramic membrane, a sort of "hybrid".

Note that tensiometers are not perfect sensors, they come with a substantial set of problems. The first is that they are going to be sensitive to salt buildup because of how water flows in and out of the tensiometers, if salt accumulates in the pores of the tensiometer's ceramic cup, it will lose its ability to properly sense the water potential of the media. This can be especially problematic if significantly hard to dissolve salts accumulate within the irrometer's structure. The second most common issue with them is their slow response, tensiometers by their very nature rely on reaching a steady state within a process that is significantly slow — water flow across a ceramic — so they will tend to respond slowly to changes in the water content of the media, as the process reaches this state.

All-in-all, if you want the absolutely best way to time irrigations of our media in hydroponics, then a tensiometer that is placed right at the root ball level of your plants will offer the best results for this, especially if you're using significant volumes of media. Tensiometers/irrometers cannot be beat when it comes to timing the watering of plants in coco or peatmoss, while they can struggle with media that are smaller, like rockwool, due to the volume that the tensiometer itself has.

The Chirp Sensor: A plug-andplay solution to moisture monitoring in hydroponics

If you want high yields in hydroponics, then you need to monitor moisture quite closely. Watering plants when they need it — and not on a timer — is critical if you want to maintain ideal water and nutrient transport within your plants. As I've discussed in a <u>previous post</u>, most of the cheap sensors available for this are inadequate as they are affected by the salts present in hydroponics and do not offer proper sensing of the amount of moisture in hydroponics media. Although there are a lot of different sensors that do offer adequate measurements — which we will be discussing in future posts these are usually not easy to use and often require custom electronics, powering and sometimes complicated calibration. In this post we are going to discuss the easiest solution if you want to have adequate moisture monitoring within your crop with least possible hassle. The chirp sensor. Note that this post has not been sponsored by Chirp's creator or anyone else.



The Chirp moisture sensor

The Chirp sensors were created a couple of years back. They are available for purchase here. The sensors use a capacitive measuring principle, which means that the sensor detects moisture by a change in the capacitance of the media in the presence of water, rather than by a change of electrical resistance, and, therefore, the sensor is not strongly affected by the salts present in hydroponics. Additionally, the sensor plates are not corroded by the flow of current between the electrodes. The plates of the sensor are actually covered in an insulating material, giving the sensor the ability to last for a long time. The big advantage of the Chirp alarm sensor is also how easy it is to set up and how useful it can be to growers.

In order to set up the sensor, you will need to put it in the media at the point where the media will require watering, you then wait a couple of minutes for the sensor reading to stabilize and you will then press the button at the top of the sensor in order to indicate that this is the threshold for

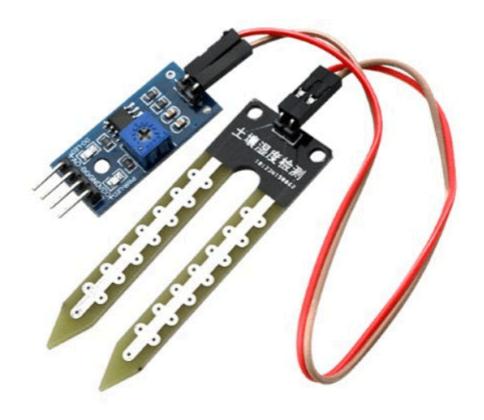
moisture where the sensor will start "chirping". Whenever the sensor reaches this reading again it will start chirping, chirping louder and more frequently as the moisture level drops below this point. It will also only do so when it detects light, so it will not detect the need for watering when the lights are out. When it chirps, you water, that's it.

If you want to figure out when to set up the sensor for watering, you can set up a pot with media (with no plants), water it till there is consistent run-off, wait for the run-off to stop, weight it — this will be the saturated weight — then weight it again every hour to quantitatively measure the dry-back of the media. You can then set up the chirp sensor when 60-70% of the water weight has been lost, which indicates a condition where watering is going to be necessary. This measurement can then be used for the watering of your plants, deeper or shallower dry-backs might be optimal depending on your conditions, but the above is a good starting point where you will not risk overwatering your plants.

The advantage of the Chirp sensor is that all of this can be done without any fancy setup, so it can be as good for watering a single plant as it could be for an entire greenhouse if enough Chirp sensors are used. Additionally, the Chirp sensors are also i2C compatible, so if you buy Chirp alarm sensors to perform this sort of monitoring you will still be able to hook them up to Arduinos or other microcontrollers in the future in order to perform your own quantitative moisture measurements and automate the entire watering cycle. If you're looking for a low-cost, reliable yet expandable plug-and-play solution for moisture monitoring then the Chirp sensor is the way to go.

How to identify resistive moisture sensors and why to never use them in hydroponics

The measuring of media moisture, also known as water-content, is critical to successfully irrigating crops in hydroponics. Badly timed irrigations cause lots of the problems faced by novice and even some large scale hydroponic growers. Trying to time irrigations at regular intervals often leads to failure because of how the water demand of a plant changes with size and environmental conditions. It is therefore critical to use a quantitative input that truly represents the amount of water in the media in order to decide whether to water or not. Sadly, the most common method to do this is through the use of resistive moisture sensors; a type of sensor that is ill-fitted for this task in hydroponics. Through this post, I will talk about how resistive sensors work, how you can identify them and why you should never use them to measure water content in your hydroponic crop.

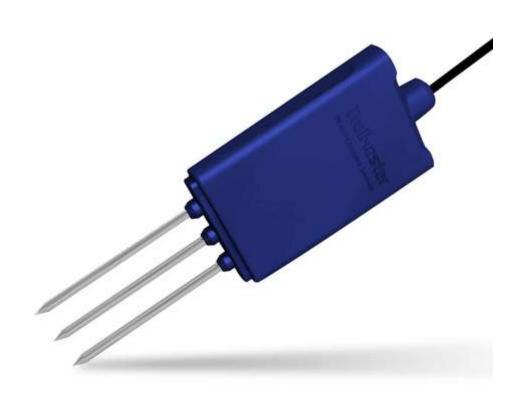


A typical resistivity sensor for measuring moisture content in soil/media

In order to measure the amount of water in media, we need to measure a property of the media that changes in proportion to how wet it is. One of the simplest approaches to this is to put two electrodes inside the media and measure the amount of resistance to the flow of electricity between these electrodes. This exploits the difference in conductivity between water and air. When the media is wet the electrodes will experience more current flow between them. On the other hand, when the media is dry, there will be more air and, therefore, less current flowing between the electrodes. This type of sensor, where we assume that the current flow between two electrodes at a fixed potential is proportional to the amount of moisture in the soil, is what we call a resistivity moisture sensor.

There are several problems with these measurements, especially

in hydroponics. The most important is that hydroponic nutrient solutions are significantly more conductive than tap water and therefore the amount of current that flows through the electrodes of the sensor will be much larger than the amount the electrodes were designed for. Since current is flowing, chemical reactions will also happen at the electrodes, corroding them and changing the measurement of resistance with time as corroded electrodes become less conductive. Due to this fact, electrode performance will deteriorate with time and the electrodes will often become useless.



A more advanced resistive sensor that uses AC and stainless steel electrodes to avoid the durability issues faced by cheaper sensors like the one in the previous image.

Some manufacturers will try to reduce the above issue by creating electrodes using less easily corroded materials, such as stainless steel, and using AC instead of DC to measure resistivity. This might partially solve the issue of the

electrodes being damaged with time but another issue arises; the conductivity of the solution is generally not constant with time as the amount of salts within the media changes. Imagine you start watering a crop with a solution that has a conductivity of 2.1mS/cm, you will then determine the measurement that corresponds to this value in the resistive sensor as "wet" but as you continue feeding salts might accumulate in the media and the conductivity in the root zone might actually be 3.0mS/cm when watering. This means that the "wet" measurement of the sensor is now greatly below the expected conductivity and therefore the sensor will fail to correctly tell you how much water there is in the media.

While resistive sensors might be able to tell between fully dry or fully wet conditions in their first use, this ability will deteriorate with time as the conductivity of the media changes or the electrodes deteriorate. Since in hydroponics we often rely on the accurate measurement of pretty specific dry back conditions in order to properly water plants, having a sensor that lacks a good degree of granularity in measuring water content is not acceptable. For this reason you should avoid sensors that use resistivity as their way to tell how much moisture there is in your media.

Thankfully telling whether a water-content sensor is a resistivity-based sensor is pretty easy. Almost all resistive sensors will contain metallic legs that are used to penetrate the media, so any sensor that uses metallic prongs like the ones showed in the two electrode examples above is most likely a sensor that uses electrical resistance to measure water-content. Sensors like this should always be avoided.

Which sensors should you use then? Within the next several posts I will be going deeper into other types of moisture sensors. I will describe other ways to measure moisture content that are better suited for hydroponics and give you some links to sensors you can get to carry out this task successfully.

Five tips to succeed when doing Kratky hydroponics

Passive hydroponic growing has become very popular during the past 10 years as it has a very low starting cost and uses no electricity. However, growing without active nutrient circulation, aeration and solution monitoring can cause significant problems, many of which can lead to crop failure. In this post I want to give you five tips that should help you with your passive growing experience and should allow you to go through your first Kratky crop with hopefully less problems.

1. It's all about height and volume per plant. In a Kratky system, successfully growing plants requires the level of the solution to go down with time to allow the roots to develop structures to obtain oxygen from the air as the solution level drops. Have too much volume per plant and this does not happen quickly enough and the plant dies from water logging, have too little volume and the solution goes down too fast and the plant dies. The exact volume per plant and container dimensions depend on the environmental conditions — which determine the plant's demand for water — but some rules of thumb have been established. For your first experience, a 4 liter bottle can be used to successfully grow a head of lettuce through its entire lifetime. You can check this and more suggestions for more complex setups in Kratky's 2008 paper.

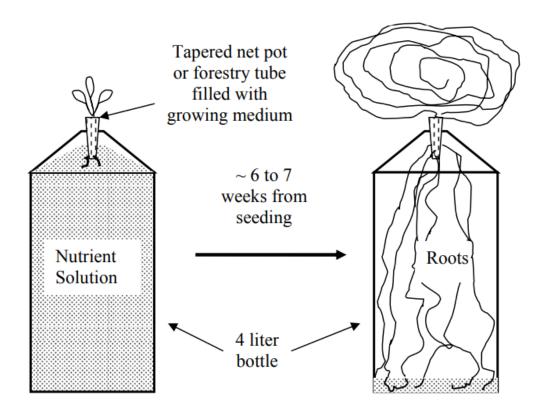


Fig. 2. Lettuce growing in a 4-liter plastic bottle.

Figure taken from Kratky's 2008 paper, cited above.

- 2. Be careful about the starting level. Another critical issue for a Kratky system is to make sure that the water level just barely touches the bottom of the receptacle where the seedling is placed or germinated. If the pot where the seedling resides is soaked with nutrient solution then the roots will never have access to enough oxygen and the seedlings will die. It is fundamental to allow the media where the plant is placed to wick water but to allow enough air space for the seedling at this stage.
- 3. Start with a lower nutrient dosage. Since the passive system will concentrate the nutrient solution as a function of time, the strength of the nutrients will go up a lot which will fit nicely with the ability of the plant to deal with more concentrated solutions. Starting with a nutrient solution that is too strong can cause the solution to become unbearable for the plant as the solution becomes more and more concentrated. This is why it is necessary to start at a lower

strength. In general, starting with a solution with an EC of around 0.6-0.8mS/cm is good since the solution will become around 4-5 times more concentrated by the end of the growth cycle.

4. Starting at a lower pH can be better. Plants like lettuce will generally want to try to increase the pH of a solution as a function of time, as they will absorb nitrates more aggressively, causing the nutrient solution to become more and more basic. Lettuce can be grown at lower pH levels with fewer problems than at higher pH levels, reason why it can be beneficial to start the solution at a pH of 4.5-5.0 so that it can increase gradually and reach 7-7.5 by the end of the growing cycle.

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Example of Kratky lettuce, taken from this blog.

5. Disinfect the water before preparing nutrients. The Kratky method is very vulnerable to plant pathogens due to the fact that the solution remains unchanged through the entire growing period. If the solution contains any bacteria or fungal spores, these can prosper aggressively within the growing cycle. If you're aiming for a purely hydroponic experience with no bacteria or fungal content, you can alleviate this problem by disinfecting the solution before preparing your nutrients. This can be done by adding a couple of drops of household bleach per liter - allowing the solution to rest for a day after that before preparing nutrients — or by running the water through a UV treatment. Inline UV treatment filters for aquariums are cheaply available online, you only need to pass the solution through them once. Boiling the water is not something I would recommend, as this also removes all the dissolved oxygen from it, which can be hard to recover without a lot of aeration, which can reintroduce pathogens into the water.

There are many more things to consider to run a successful

Kratky setup but I hope the above tips do help you avoid some common pitfalls and establish your first completely passive, hydroponic growing method. All the above mentioned issues can get substantially harder when growing larger plants, so starting with smaller plants that are easier to handle — such as lettuce — is always a sure way to increase your chances of success.

Practical use of ion selective electrodes in hydroponics

The achievement of adequate ion concentrations in nutrient solutions, media and plant tissue is key to success in hydroponics. It is therefore important to measure them, so that proper values can be maintained. Up until now, this has been mostly achieved with the use of external lab testing but electrochemical developments made during the past 10 years have made the production of ion selective electrodes with high enough selectivity coefficients viable at a large scale. This means that it is now possible to obtain sensors that yield accurate enough measurements of nitrate, potassium and calcium concentrations, which allows for routine monitoring of these values without having to worry too much about complicated electrode calibration that accounts for selectivity issues. In today's article I am going to be talking about these electrodes and how they can be used in hydroponic crops.



A potassium ion selective electrode manufactured by Horiba An ion selective electrode is an electrochemical device that is sensitive to the concentration of a single ion in solution. This is commonly achieved by coating an electrode with a molecule that can uniquely accommodate that ion, so that the potential measured across that electrode and a reference electrode will change proportionally to the concentration of that ion. A pH electrode achieves this effect with glass — a pH electrode is basically an H_3O^+ ion selective electrode — while to sense other ions the use of other molecules is required. For example Valinomycin — a molecule originally developed as an anti-biotic — is able to accommodate K^+ ions very selectively, reason why an electrode coated with a Valinomycin containing membrane will be sensitive to changes in K^+ concentration.

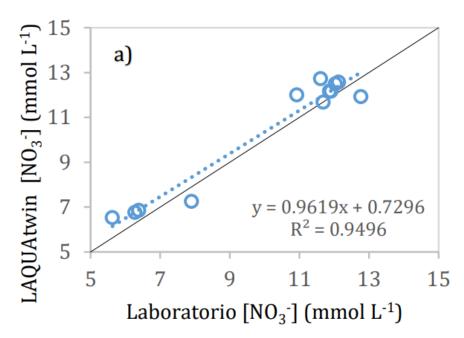
The issue with using these electrodes in hydroponics has always been two fold. First, the electrodes were commonly very expensive (thousands of dollars per electrode) and second, the selectivity of the electrodes was limited enough that the concentrations of other ions in hydroponic solutions caused substantial interference. This meant that accurate use in hydroponics required someone with analytical chemistry training that would calibrate the electrodes to variations in a single ion against a more complicated ionic background, a process which greatly limited the applicability of the technology. However, companies like Horiba have now developed electrodes that overcome both of these issues, with electrodes that have high selectivity coupled with very attractive prices. You can see Horiba's ion selective electrodes for potassium, calcium and nitrate in the links below. These electrodes are very simple to use and come with solutions to perform 2 point calibrations which are good enough given their high selectivity.

Note that Horiba is *not* sponsoring this content, but the links below are amazon affiliate links that will help support this blog at no extra cost to you, if you decide to purchase them.

- Potassium selective electrode
- Nitrate selective electrode
- <u>Calcium selective electrode</u>

Are these electrodes good enough for hydroponics? The answer is, yes! This independent <u>Spanish research thesis</u> looked at the use of two different brands of ion selective electrode for the determination of potassium, calcium and nitrate in hydroponic solutions. Their results show that the Horiba probes achieve good accuracy in the determination of all of these ions, correlating very well with lab measurements of the same nutrient solutions. With these probes you can therefore monitor the concentrations of K, Ca and N as nitrate as a function of time, giving you substantial information about the accuracy of your solution preparations and — probably most importantly in the case of Ca — information about how your water supply calcium content is changing through time, which can be very important if you're using tap water to prepare

your hydroponic solutions. The determinations are instantaneous, which gives you the ability to quickly react, without the need to wait for a long time for lab analysis to come back.



Results for lab measured Vs probe measured nitrate concentrations for hydroponic nutrient solutions using the Horiba probes.

Another very interesting use of these ion selective electrodes is for the monitoring of plant sap to measure nutrient concentrations in tissue. This can be achieved by collecting petiole tissue from mature leaves to perform an extraction — using a garlic press — which then generates sap that can be measured directly using the electrodes. This gives you the ability to perform a lot of tissue measurements, allowing you not only to look at nutrient concentrations of a single plant, but to monitor tissue concentrations from different plants or even different zones in the same plant. You can obtain results from the analysis right away, which allows for much quicker actions to be taken if required. Horiba shows some examples of how this sap analysis can be carried out here.

Although the information given by the above electrodes is not perfect, it has the advantage of being instantaneous and known to correlate very well with lab results measured using ICP.

The ability to carry out 10x more analysis and to monitor these three ions way more closely in tissue, nutrient solutions, run-off, foliar sprays, etc, opens up a lot of ways to improve crop nutrition and to see problems coming way before they become major issues. Imagine being able to monitor the K, Ca and nitrate concentration in your solutions and plant tissue daily, instead of once a week, month or even sometimes even only once per crop cycle, for a fraction of the cost.

Inner leaf tipburn in hydroponic lettuce

The most common problem I get contacted for by hydroponic lettuce growers is the appearance of inner leaf tipburn within their plants. During the past 10 years I have consulted for dozens of growers and helped many of them solve this issue. There can be multiple causes for the problem but a careful evaluation of the crop can often lead to a viable solution. In today's article I am going to talk about the main reasons why inner leaf tipburn is such a big problem with hydroponic lettuce, what can cause it and how it can be fixed.

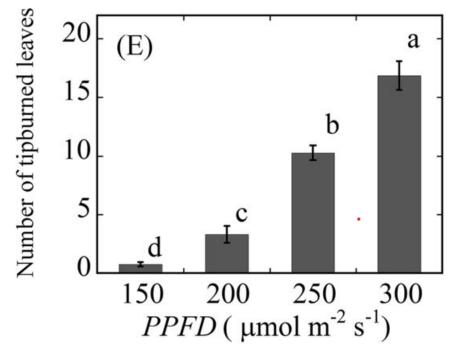


Lettuce showing classic inner leaf tipburn. Image was taken from this article (8)

What is this leaf tipburn issue? It appears as lettuce heads become adult plants, the tips of the inner lettuce leaves die off. This happens because of a lack of enough calcium at the edges of the leaves, which causes the rapidly growing tissue at the center of the lettuce head to start dying of. This does not happen at the outer leaves of the plant because these leaves get much more efficient nutrient transport, while the inner leaves receive a much more limited amount of calcium. In most hydroponic cases this is actually not related at all with a lack of calcium in the nutrient solution, but with the transport of the Calcium from the solution to the leaves. It is often the case in hydroponic crops that conditions are so favorable for fast growth that the leaves of the plant grow too fast and Calcium transport just cannot keep up (5, 6).

Due to the above it is common for measures that help with Ca absorption to also help with the elimination of this tipburn phenomenon. An effective change in the nutrient solution is to reduce the K:Ca ratio if this ratio is significantly high. Going from a solution that has a high ratio (say 3:1) to a solution with a ratio closer to 1.25:1 can heavily reduce tip

burn by reducing the competition of K with Ca and facilitating Ca transport. Making it easier for the plant to move nutrients by reducing the EC of the solution can often lead to improvements in this issue, this is both because lower EC values reduce overall nutrient absorption, making growth slower, therefore enabling the Ca to be absorbed to meet the needs of the plant. You can see experimental evidence for the two suggestions above in (1). This is why lettuce formulated nutrients will generally have K:Ca ratios close to 1.25:1 and why the EC values recommended are usually in the 1-2mS/cm range, even though higher EC levels can indeed be more productive in terms of mass produced per day.



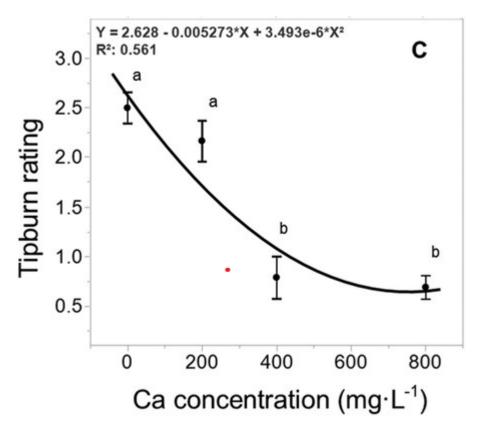
Leaves with tipburn in lettuce as a function of light intensity (taken from $\underline{2}$)

Since tipburn is related to how fast plants are grown, it is usually effective to reduce the light intensity in order to alleviate the tipburn problem (2). While growing lettuce at higher PPFD values can generate larger amounts of dry weight per day, it also correlates with a significantly larger amount of tipburn within the crop, precisely because growth is more aggressive. This, in combination with the fact that warmer temperatures further increase growth speed, is an important reason why there is significantly higher incidence of leaf

tipburn in lettuce for crops that are produced during the spring/summer (3).

Environmental modifications to increase Ca transport can also be quite successful at helping prevent leaf tipburn, these can be particularly important when the desire to maximize yields as a function of time is fundamental (for example when growing lettuce in space). Constantly blowing air directly into the inner leaves of lettuce plants has been shown to effectively prevent the tipburn issue, as the constant stream of air increases nutrient transport to the lower leaves, by increasing evaporation and replenishing carbon dioxide (3,4). Note that these experiments are usually done in enriched CO_2 environments, which is a modification that also helps with the issue.

One of the most practical approaches for the control and prevention of tip burn is also the application of calcium foliar sprays, with one of the most effective treatments — as it is also the case for many different crops — being the use of Calcium chloride (7). Treatments of crops twice a week with 400-800 ppm of Ca from calcium chloride can be quite effective in controlling tip burn with minimal decrease in yields. Additionally, calcium chloride can also be effective in the prevention of fungal disease which makes this proposition even more interesting. However, the use of foliar sprays like these requires a careful evaluation of the environmental conditions, as they can cause other problems if they are applied incorrectly.



Tip burn as a function of foliar Ca application rate. Taken from $(\frac{7}{2})$

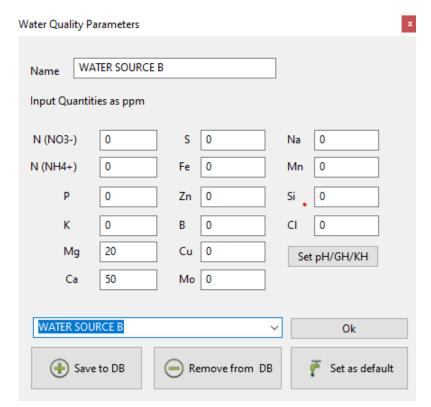
In my experience, the correction of tip burn should start with an evaluation of the nutrient solution, to evaluate if enough calcium is present in solution, if the ratios of Ca to other cations, such as Mg, K and Na is correct and if salinity due to carbonates, Na, Cl or other such ions is too high. The EC can then be evaluated to determine whether it needs to be decreased to modify the growth rate and help alleviate the issue. Once the nutrient solution aspects are considered, the environmental conditions should be carefully evaluated to determine if changes to either temperature, relative humidity, air circulation, carbon dioxide concentration or light intensity are possible and if so, if they would be helpful. If the environmental conditions allow it, a foliar spray can also be formulated to supplement calcium to the crop using a highly available calcium salt — like Ca chloride — which should also help with the transport of Ca to leaf tissue.

Characterizing hydroponic stock nutrient solutions

I've written several articles in the past about how to characterize concentrated hydroponic nutrient solutions using simple yet highly accurate small scale methods. I have now released a video showing how this is all done in practice, using the B solution I showed how to prepare in a previous video.

How tap water affects your hydroponic nutrient formulation

Tap water is often the most reliable source of water for hydroponic growers. However, especially in the North America and Europe, tap water can contain a significant amount of dissolved solids. These substances can fundamentally affect the properties of the water and require adjusting the nutrient formulation in order to achieve proper nutrient concentrations in the final nutrient solutions. In this post I'm going to walk you through some of the most important considerations when dealing with tap water and how you should adjust your nutrient formulations to make sure that the final nutrient concentrations are adequate for plant growth.



Hydrobuddy allows you to set water quality parameters to ensure they are taken into account within your calculations

There are four important factors to consider when adjusting a nutrient formulation to your tap water.

Dissolved nutrients. Tap water often contains nutrients that are used by plants. The most common ones are Calcium, Magnesium and Iron. It is often fundamental to adjust your nutrient formulation to account for their presence. If you are using HydroBuddy to prepare your nutrient formulations you can use the "Set Water Quality Parameters" dialogue to introduce the ppm concentrations of these nutrients so that they are properly added when considering your nutrient targets. This will mean that less Ca, Mg and Fe will be added from salts, because the program will assume some will come from the water. An important fact to consider is also that the Ca, Mg and Fe concentrations in the water will tend to change with the as hotter temperatures means that underground limestone/dolomite deposits will dissolve more and therefore lead to more Ca/Mg rich water. Usually I will advice people to get two analysis - one in August, one in February - so that they can know the two extremes their formulation will be at

and adjust accordingly through the year depending on the temperature of the incoming water.

Alkalinity. Your water will also contain a substantial amount of carbonates and will tend to be basic due to this reason. It is often easiest to take the amount of moles of Ca plus the moles of Mg in the water and discount this by the moles of Sulfur, then calculate how much moles of acid you will need to neutralize this amount. This makes the assumption that all Mg and Ca in the water are carbonates, except for the amount that are present as sulfates. Knowing how much moles of acid are needed to neutralize this you can now calculate how much ppm of S, N or P - depending on the acid you are going to be using - will take to neutralize the water and set this into the "Set Water Quality Parameters" box in HydroBuddy. This will account for the acid addition that will be needed to remove all alkalinity from the water when you prepare the nutrient solution. Note that although HydroBuddy contains fields to set pH/gH/kH within the program, it actually does not take into account any of these values when calculating compensations (these are just there to store for reference).

Dissolved non-nutrient minerals. There can be a lot of minerals dissolved in the water that are not nutrients, which is why a complete chemical panel of the water is required if the water source to be used hasn't been evaluated before. In particular Na, Cl and heavy metals are the most important things to look for, as these can very negatively affect your plants. High presence of these substances will often make the water completely unusable for hydroponics, unless some specific pretreatment steps are taken to fix the issue. Make sure that the ppm of Cl are below 50 ppm, Na is below 100 ppm and all heavy metals are within quantities considered safe for human use.

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Dissolved organics. Perhaps one of the least evaluated aspects of tap water, dissolved organics can be particularly important when considering a tap water source. Substances like chloramines and herbicides can be fundamentally damaging to plant roots. While it is easy to test for oxidative substances like chloramines, normally it is hard to get a lab test for most specific organic substances, reason why the best solution for this problem is adequate pretreatment. Always make sure your tap water runs through both media — sand, ceramic — and activated carbon filters before it is used in your hydroponic crop. An adequate sterilization treatment, UV, ozone, etc, can also help reduce the risk of getting organic molecule contamination.

As you can see, tap water is a complex beast. Not only do we need to account for the nutrients and non-nutrients it can contribute, but we also need to account for its alkalinity and the ways in which these three things might change through the seasons. These complications are the main reason why so many growers end up deciding to use RO water instead — higher reproducibility, less problems — but they are certainly not insurmountable. Creating a hydroponic formulation and infrastructure that accounts for these problems can lead to great cost savings, as you can save both on fertilizers — because the tap water already contains some minerals — and energy.