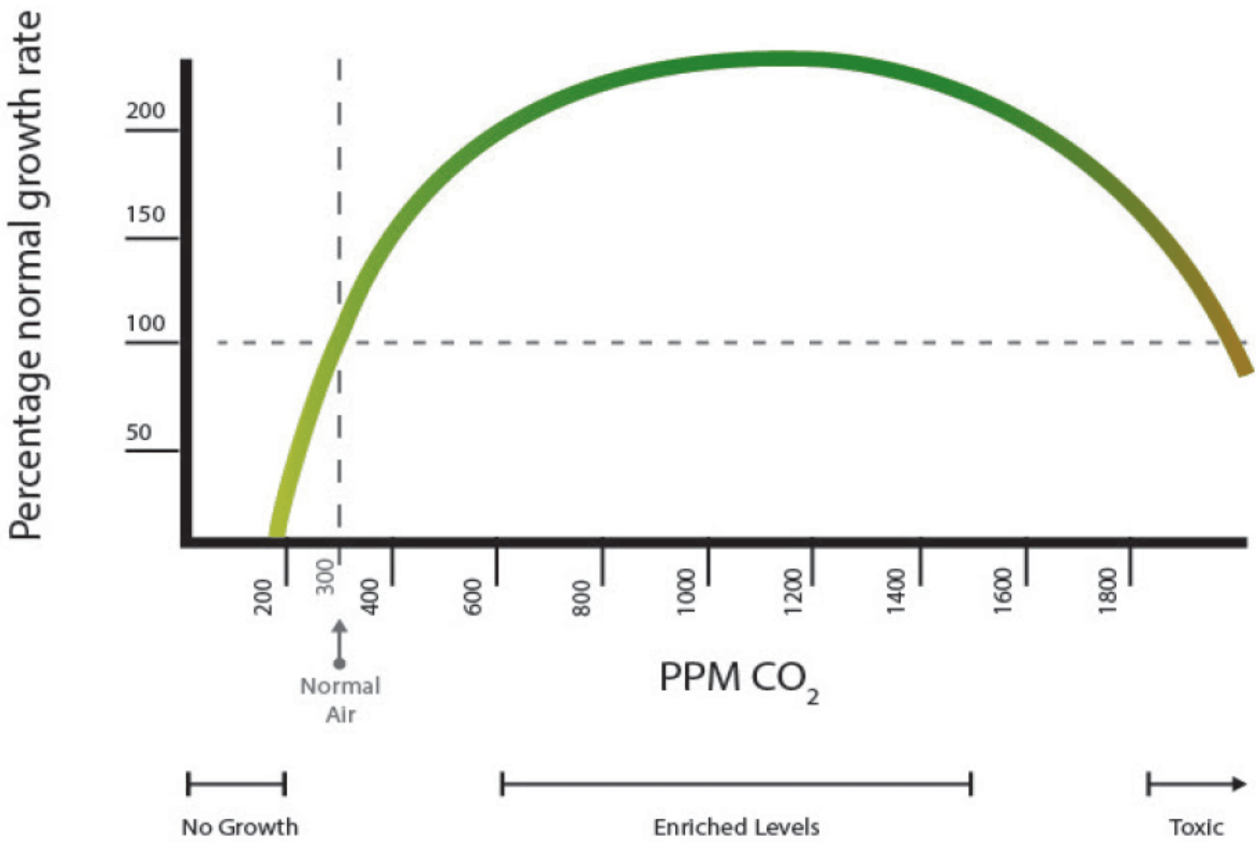
Practical aspects of carbon dioxide enrichment in hydroponics

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

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



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

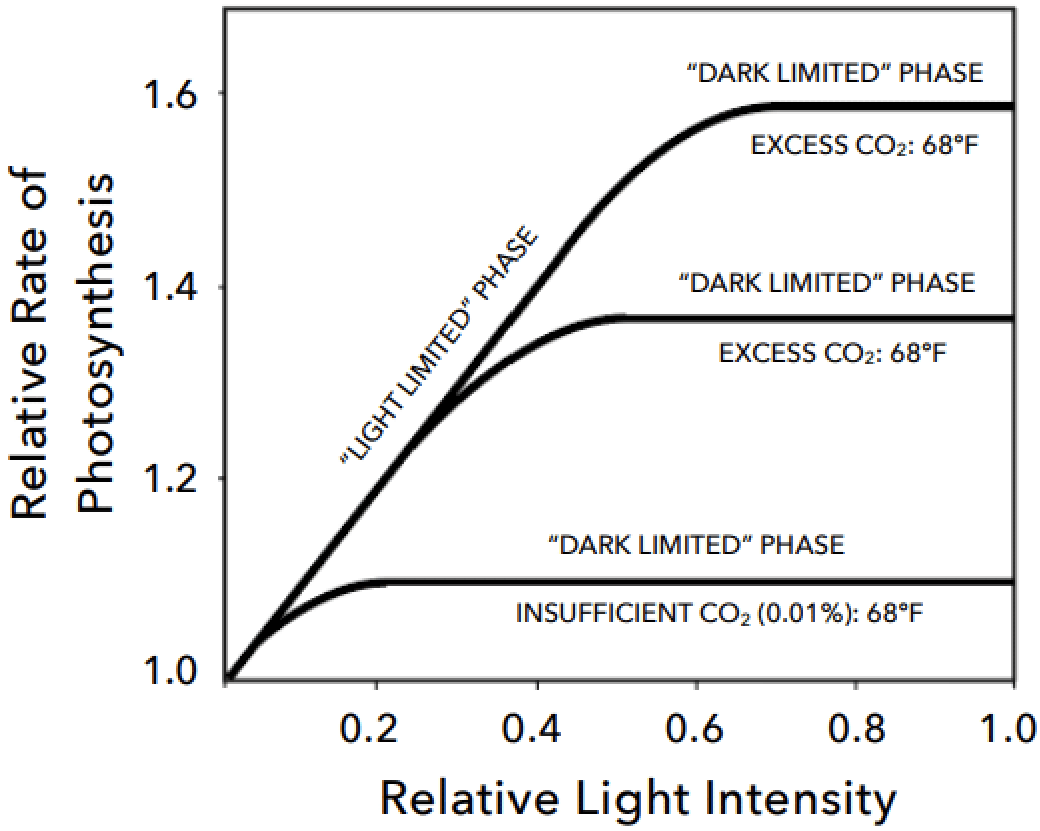
First of all, it is important to realize that carbon dioxide enrichment does not make sense under all circumstances. Plants will tend to be limited by other factors before they are limited by carbon dioxide. The first step before CO_2 enrichment is considered, is to make sure that the plants are receiving enough light (>400 µmol/m^2/s for flowering plants) and that their tissue analyses show that they are not being limited by a deficiency of any particular mineral nutrient. Plants that are either under lower light, drought stress, or nutritional deficiencies will tend to benefit significantly less from CO_2 enrichment than plants that are actually limited only by the CO2 concentration in the greenhouse. Under some of these circumstances, CO_2 injections could lead to excessive amounts of CO_2 that might lead to actually counter-productive results. Temperature can also be a key factor in determining the success of CO_2 enrichment, with temperatures in the upper range of ideal temperatures for a crop often leading to better results as the optimal temperature increases as a function of CO_2 enrichment (see here).

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

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

The sensors used to detect the CO_2 and their placement will also be very important. There are mainly optical and electrochemical sensors available for CO_2 detection. Both of these sensors need to be periodically checked against CO_2 free gases and atmospheric CO_2 to check their calibration. Optical sensors often require cleaning in order to remain reliable. Because of these potential reliability issues, it is often ideal to have multiple CO2 sensors used for control and to check the values of the sensors against each other to ensure no sensors have stopped working correctly. The CO2 distribution will usually be highest close to the ground and lower at leaf canopy, reason why sensors need to be placed around canopy height, to ensure the actual canopy concentration reaches the desirable level since this is where most CO2 will be used.

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



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

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

There is clearly a lot of research to be done, as optimal CO_2 supplementation involves many variables (including financial, environmental, nutritional, plant species, etc). An initial approach where the atmosphere is enriched to 1000 ppm of CO_2 with C3 plants that can take advantage of it, where nutrition, in general, is increased, temperatures are slightly increased as well and CO2 is vented at night is bound to give satisfactory initial results. This is a good starting point for anyone looking to benefit from CO_2 enrichment.

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

stations for hydroponics

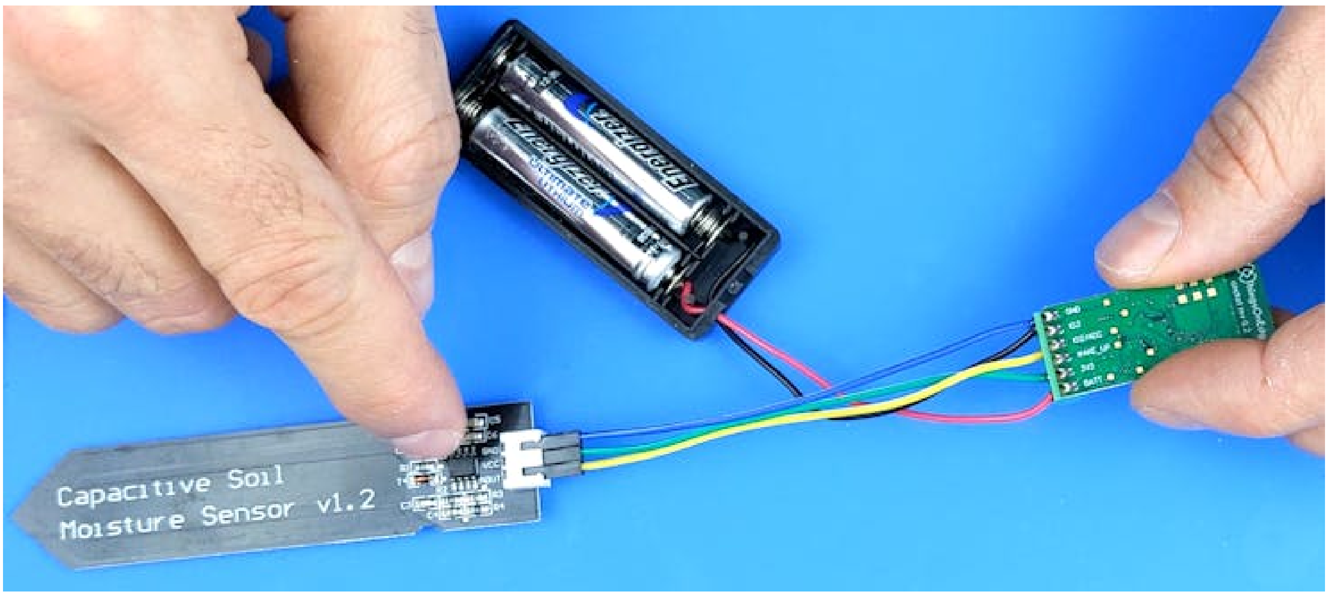
When you monitor variables in a hydroponic plant where more than a few plants exist, it becomes important to be able to deploy a wide array of sensors quickly and to be able to set them up without having to lay down a couple of miles of wire in your growing rooms or greenhouses. For this reason, I have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

The cricket IoT board by ThingsOnEdge

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

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

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



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

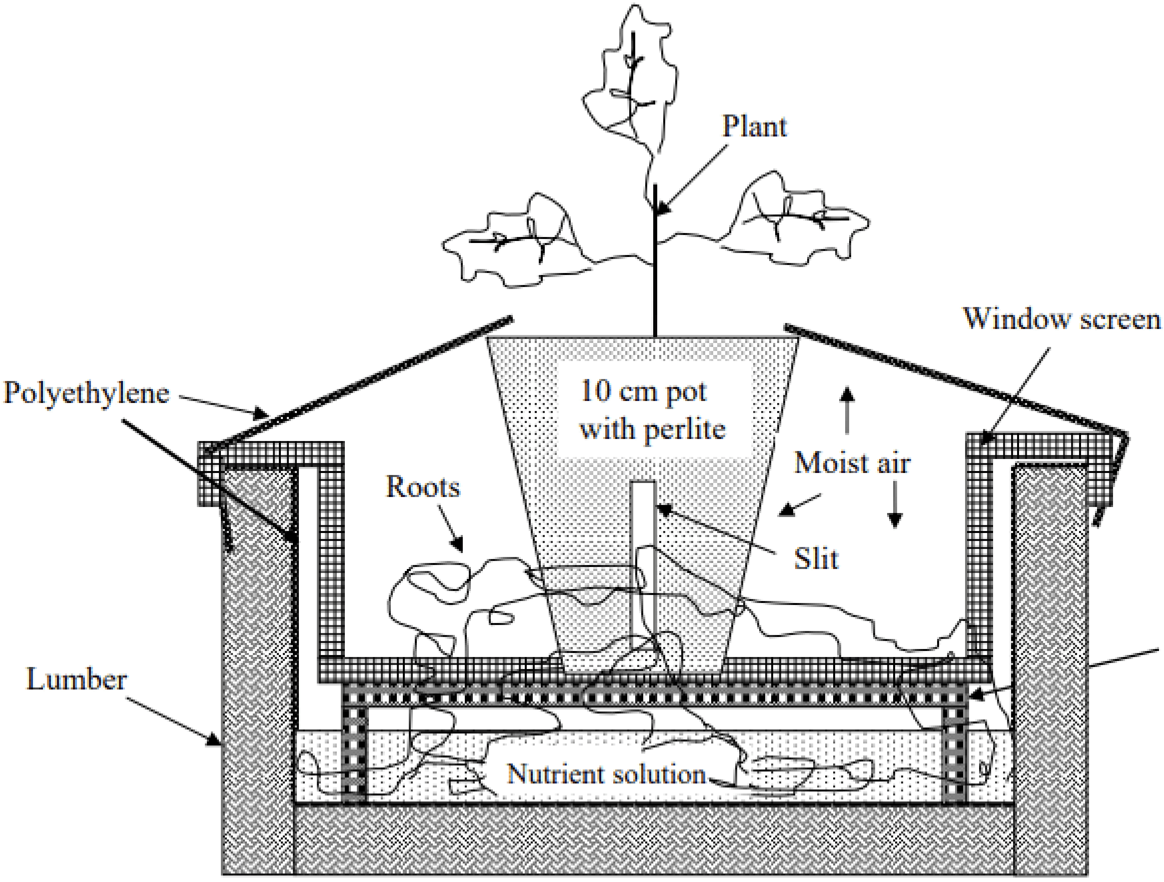
One of the disadvantages of the cricket – the main reason why it won't fully replace other boards for me – is that it only has one analog sensor and one digital sensor input. This means that you're limited to only two sensors per cricket and you also have an inability to use more advanced input protocols, such as the i2c protocol that is used by a wide variety of sensors. If you lack i2c it means you're going to miss the opportunity to use a lot of advanced sensors, many of which I consider basic in a hydroponic setup, such as the BME280 sensors (see here why).

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

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 (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 2005 Kratky paper 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.

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 high-salinity, 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. I*t 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.

The Chirp Sensor: A plug-and-play 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 previous post, 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.**

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.

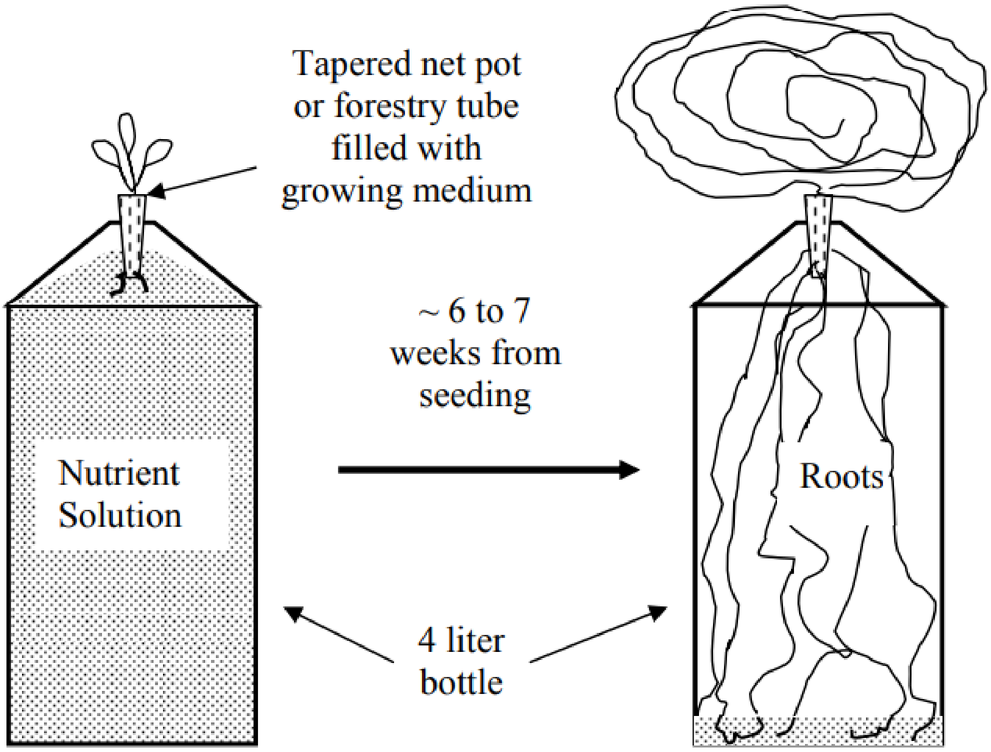


Fig. 2. Lettuce growing in a 4-liter plastic bottle.

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.

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

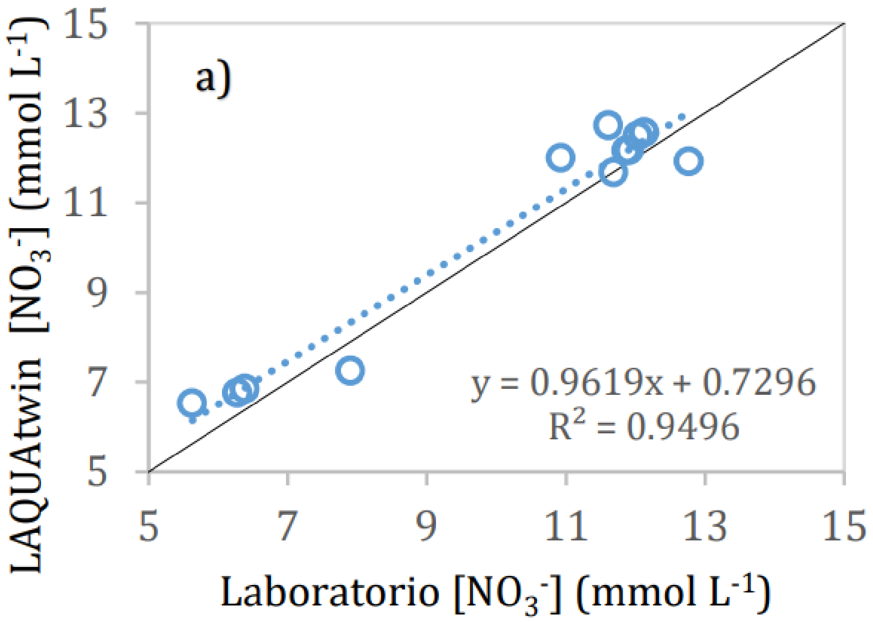
An ion selective electrode is an electrochemical device that is sensitive to the concentration of a single ion in solution. This is commonly achieved by coating an electrode with a molecule that can uniquely accommodate that ion, so that the potential measured across that electrode and a reference electrode 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
- Calcium selective electrode

Are these electrodes good enough for hydroponics? The answer is, yes! This independent Spanish research thesis 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.

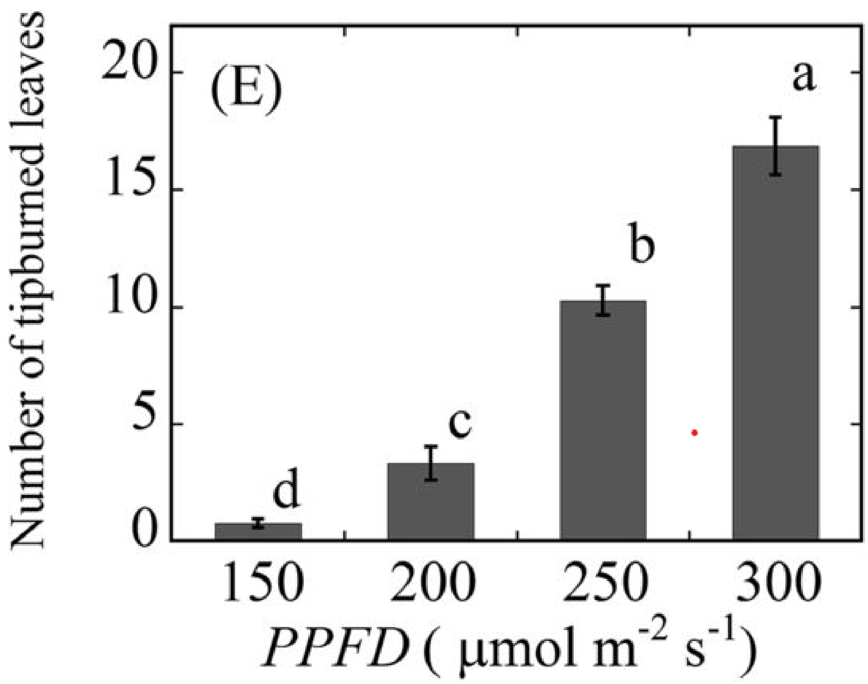
Inner leaf tipburn in hydroponic lettuce

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.

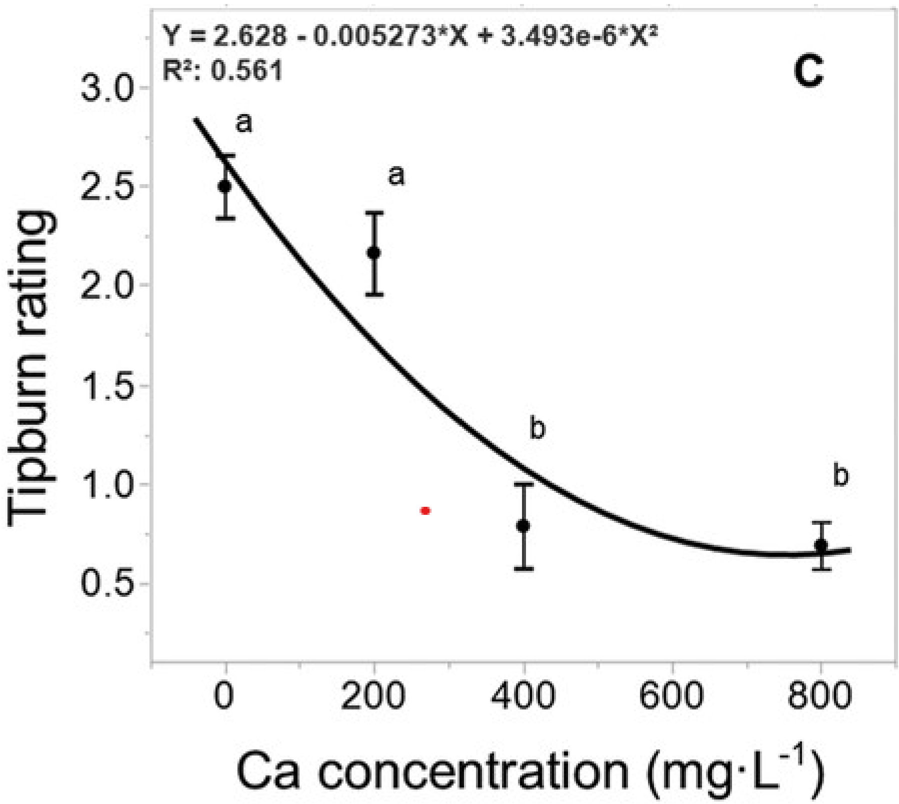


Leaves with tipburn in lettuce as a function of light intensity (taken from 2)

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 (7)

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.

The effect of Seaweed/Kelp extracts in plants

Few bio-stimulants are more popularly used than seaweed/kelp extracts. These are used by many growers to increase plant quality and yields, in particular, extracts from the *Ascophyllum nodosum* species are an all-time favorite of the industry. These extract have also been studied extensively for the past 40 years, with large amounts of evidence gathered about their effects and properties across several different plant species. In this article, I will be talking about what the research says about their use, why these extracts work, how these have usually been applied and what you should be looking for when using this type of bio-stimulant.

Composition of the seaweeds extracts Maxicrop and Algifert (content in mg kg^{-1}). The content of dry matter in the liquid extract of Maxicrop is 8.0-8.2%. *Source:* Alternatieve Landbouwmethoden (1977).

Element	Maxicrop	Algifert
N	7 200	8 700
P	9 000	1 400
K	26 000	19 000
Mg	3 500	10 600
Fe	2 200	60
Al	60	20
Ca	3 500	11 900
S	23 000	49 600
Cl	67 000	55 400
Si	1 000	1 000
Na	70 000	19 400
I	900	200
Br	800	0.6
Cu	40	0.5
Co	4	2
Ni	24	5
Zn	100	33
Mo	10	0.6
Mn	40	24
B	1	50

Composition of some seaweed extracts in 1991 (taken from (1) linked below)

The use of kelp extracts is so common, that there was already enough research done about their use to publish a review on the subject in 1991 (1), a lot of the information below comes from this source. Seaweed has been used by farmers for hundreds of years, as it could be used as an alternative to lime in order to alkalinize acidic peatmoss soils, due to the high basicity of seaweed extracts (as some are very high in calcium carbonate content). Seaweed extracts also contain a lot of micro and macro nutrients – as shown above – in proportions that are useful for their use as fertilizer. They are a significant source of potassium and calcium, although the variability of the composition – as shown in the table above – can be quite important. They also contain micronutrients but their low presence relative to plant needs implies that the positive effects of the extracts are most likely not due to them.

Perhaps one of the most important factors surrounding seaweeds is their content of bioactive molecules. These extracts contain an important array of cytokinins, which are plant hormones that will significantly affect plant growth. Auxins, gibberillin-like substances and ethylene precursors like aminocyclopropanecarboxylic acid, have also been detected in seaweed extracts. The cytokinins are usually present in concentrations of around 2-20 ppm in the concentrated extracts, which are enough to cause effects, even if the final diluted versions will be at much lower concentrations. The application of seaweed extracts is usually done through an entire crop cycle and is usually cumulative in nature.

Application rate, frequency, seaweed species and extract processing methods can substantially affect results, with many contradictory results showing up in the literature, with some people showing increases in growth and yields while others show no effects at all. The review quoted above describes many examples of positive results, including examples showing weight gains, yield gains and increases in certain nutrients, like P and N. The review also talks about the ability of seaweed extracts to increase resistance to pests and improve crop quality. A more recent review from 2014 (2) further expands on a lot of these positive effects, citing extensive literature showing increases in yields, dry weights and quality for a wide variety of plant species. *In total, more than 30 different papers showing increases in yields due to the use of kelp extracts are cited in this review.* There are also more than 20 articles cited describing increases in disease resistance or other mechanisms of defense elicitation due to the use of the seaweed extracts.

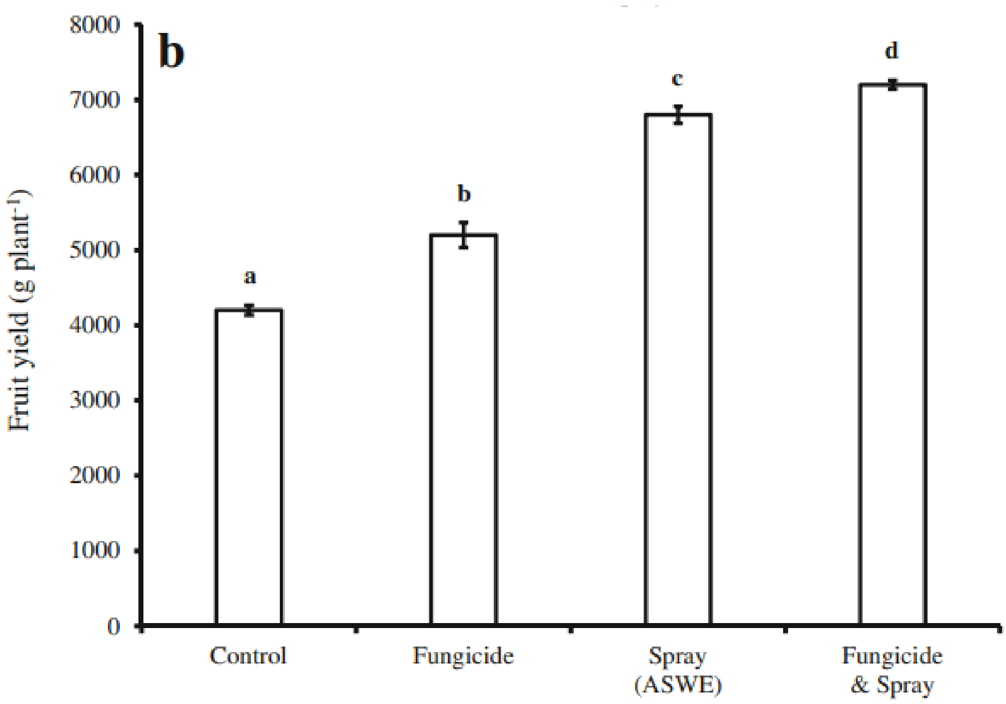


Fig. 2 Fruit yield of field-grown tomato plants from **a** field experiment 1, 90 days after transplantation with eight treatments including seaweed extract made from *A. nodosum* (ASWE) at a concentration of 0.2 % and **b** field experiment 2, 120 days after transplantation with four treatments, including ASWE at a concentration of 0.5 %. Yields are g plant^{-1} of fresh weight accumulated over several harvests. Data are means±SE (n=30 plants); *different letters* according to Fisher's Least Significant Difference (LSD) test (P=0.05); LSD is 372.3 and 306.1 for **a** and **b**, respectively

Results of a seaweed extract application in tomatoes (taken from (3))

Foliar applications of seaweed can be carried out at varied levels of frequency and concentration. Applications at a 0.2-0.5% w/v of dry extracts are most common, although higher or lower concentrations have also been found to be effective. As a root drench applications will tend to be on the lower side, as the seaweed contains a substantial amount of NaCl, which can be damaging to plants. Timing of applications can also be quite critical, some growers apply the extract equally spaced through the entire growing periods, while others attempt to time the application with a specific growth phase. Success is reported in both cases, although papers that describe different timing of single applications often find significant differences. To arrive at the optimal usage for a plant species it will be necessary to carry out tests with single applications at different intervals, although single weekly applications are likely to be successful if a less involved approach is desired.

Although the use of seaweed extracts can be very positive, it is also worth mentioning that it is very dependent on the quality and consistency of the extract being produced. Since we know that most of the positive effects of these seaweeds are related to their plant hormone content, their use can sometimes be replaced with specific applications of plant hormones, if the effects are properly understood. The discussion in (2) cited before points to the fact that kinetin applications have been able to match the effects of kelp extracts, at a fraction of the cost and the environmental impact at least in a few cases.

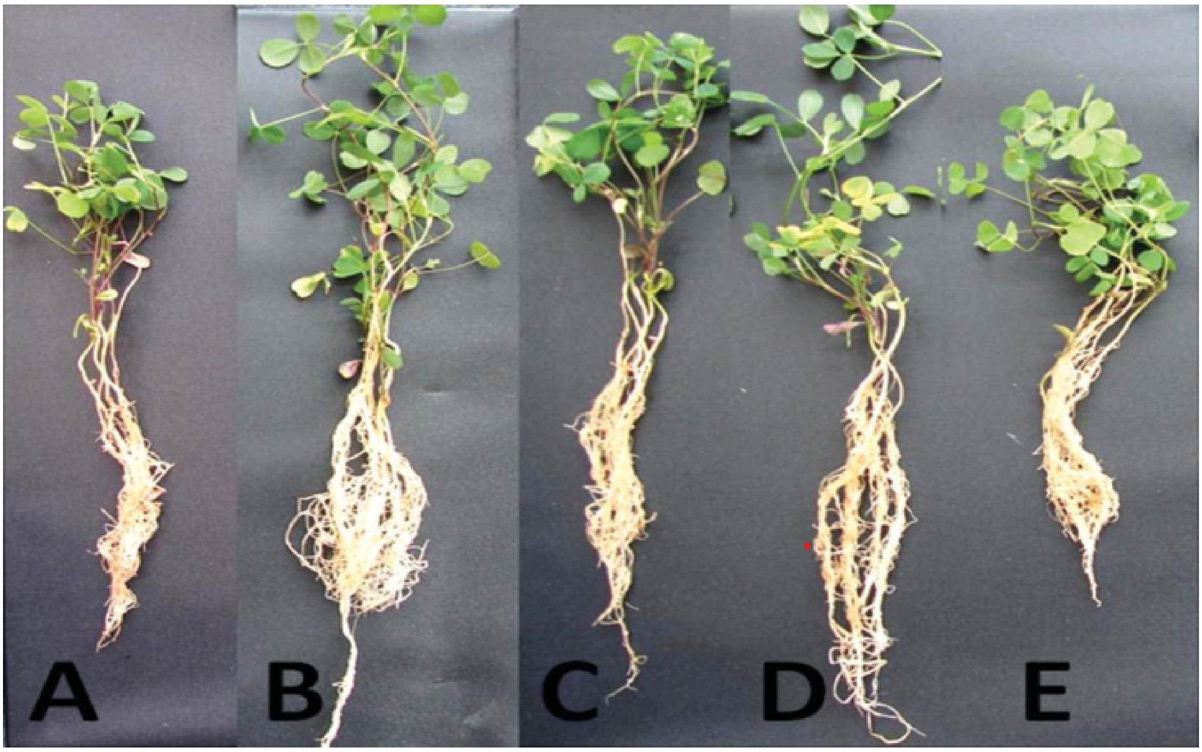


Fig 1: Effects of 1 g L"1, *Ascophyllum nodosum* extract (ANE) and its organic sub-fractions on root nodulation growth and development of alfalfa plants 6 weeks after the treatment: (a) control, (b) *Ascophyllum nodosum* extract (ANE) (c) methanol extract, (d) chloroform, and (e) ethyl acetate. (Khan *et al*. 2013).

Photographs showing the effect of kelp extract on root nodulation in alfalfa. Taken from this review (4)

With all the above said, it is quite evident that kelp/seaweed extracts have been widely confirmed to have positive effects in the growing of plants, beyond any reasonable doubt. This effect is mostly related with the hormones they contain and is therefore dependent on the seaweed species, where it is grown and how the seaweed powder is generated. Although root and foliar applications of kelp can both be used to improve results, the use of foliar applications is often favored in order to avoid the introduction of some undesired ions into the growing media. **If you're not using kelp, go ahead, it's bound to help!**

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.