NIR Devices for Leaf Tissue Mineral Analysis

Traditional leaf tissue analysis can cost 50 to 150 USD per sample and take weeks to complete, forcing growers to make nutrient decisions based on outdated information. Near infrared (NIR) spectroscopy devices could theoretically change this reality by providing real time, on site mineral analysis of leaf tissues at a fraction of the cost and time required by conventional laboratory methods.

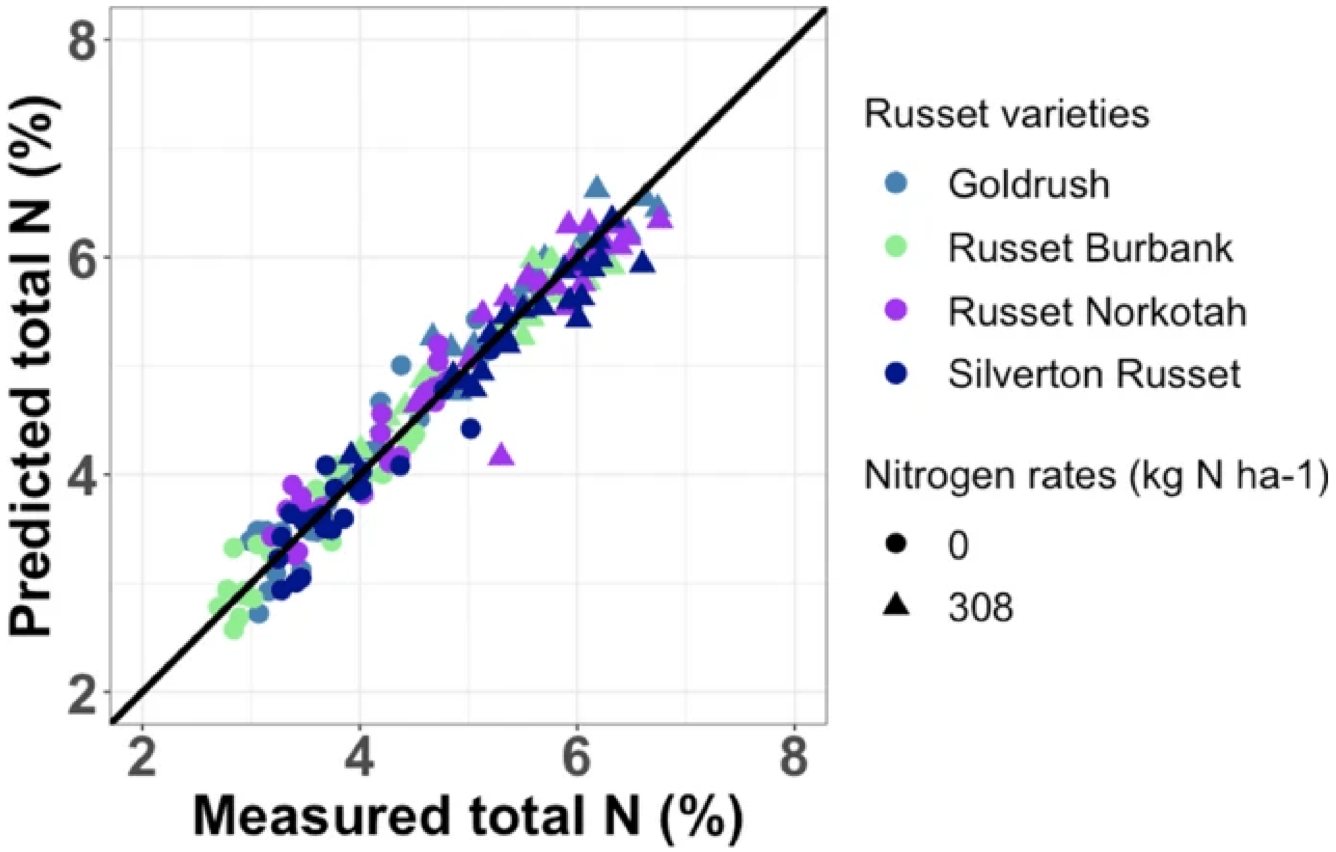


Image showing NIR measured Vs predicted N values for potatoes, taken from (7)

The Science Behind NIR Technology

Near infrared spectroscopy operates in the electromagnetic spectrum between 700 and 2500 nanometers, measuring the absorption of light by molecular bonds in plant tissues. The technique works by exploiting the fact that organic compounds containing carbon hydrogen (C-H), oxygen hydrogen (O-H), and nitrogen hydrogen (N-H) bonds absorb specific wavelengths of NIR light (1).

The fundamental principle relies on the relationship between chemical composition and spectral signatures. When NIR light penetrates leaf tissue, different molecules absorb energy at characteristic wavelengths, creating a unique spectral fingerprint. Mathematical models, typically using partial least squares regression (PLSR), then correlate these spectral patterns with actual mineral concentrations determined through traditional analytical methods (2).

Importantly, NIR technology detects macronutrients like nitrogen, phosphorus, and sulfur directly because they are major constituents of NIR sensitive organic compounds such as proteins, nucleic acids, and amino acids. In contrast, nutrients that exist primarily in inorganic forms like calcium, magnesium, and potassium are detected indirectly through their associations with organic compounds (3).

Expected Accuracy Levels

Recent studies show that NIR spectroscopy can achieve excellent prediction accuracy for macronutrients, with correlation coefficients (R^2) typically ranging from 0.80 to 0.95 for nitrogen, phosphorus, and potassium in various crop species (4). Micronutrients generally show lower accuracy, with R^2 values between 0.60 to 0.85, due to their lower concentrations and weaker correlations with NIR active organic compounds.

The ratio of performance to deviation (RPD) values provide another measure of model reliability. RPD values above 2.0 indicate good to excellent predictions, while values above 3.0 are considered excellent for analytical purposes (5). Most successful NIR calibrations for major nutrients achieve RPD values between 2.5 and 4.0, making them suitable for practical nutrient management decisions.

However, accuracy varies significantly based on sample preparation and measurement conditions. Dried and ground leaf samples consistently produce better calibrations compared to fresh leaves, with improvements in R^2 values of 0.10 to 0.20 for most nutrients. This standardization eliminates moisture content variability and particle size effects that can interfere with spectral measurements (6).

Calibration Challenges and Requirements

Developing robust NIR calibrations requires extensive datasets spanning the full range of nutrient concentrations likely to be encountered in practice. Most successful models require 100 to 300 calibration samples representing different varieties, growth conditions, and nutritional states. The quality of reference analytical data used for calibration directly impacts the final model accuracy, making precise laboratory analysis of training samples essential.

Spectral preprocessing represents another critical calibration challenge. Raw NIR spectra contain noise from light scattering, baseline shifts, and instrument variability that must be corrected before model development. Common preprocessing methods include multiplicative scatter correction (MSC), standard normal variate (SNV), and various derivative transformations, with the optimal approach varying by crop species and nutrient (7).

Model transferability between different instruments, locations, and time periods poses ongoing challenges. Calibrations developed for one NIR device often require recalibration when applied to different instruments, even from the same manufacturer. This limitation necessitates either standardization procedures or the development of universal calibration models that work across multiple platforms.

Real World Application Issues

Field deployment of NIR devices introduces additional complications not encountered in laboratory settings. Temperature variations can significantly affect spectral measurements, as changing temperatures alter the abundance of organic compounds in plant tissues and the optical properties of the instrument itself (8).

Moisture content represents perhaps the most significant challenge for in field NIR analysis. Water absorption bands can overwhelm nutrient signals in fresh leaf tissue, reducing prediction accuracy by 20 to 40% compared to dried samples. Some portable NIR devices attempt to compensate through moisture correction algorithms, but these approaches add complexity and potential error sources.

Plant species specificity also limits practical implementation. Most NIR calibrations work best for the specific crop and varieties used in model development. Attempting to apply potato leaf calibrations to tomato plants, for example, typically results in poor accuracy. This specificity requirement means that commercial operations need either species specific calibrations or must accept reduced accuracy when using general purpose models.

Comparison with Traditional Analytical Techniques

Parameter	NIR Spectroscopy	ICP-OES	Atomic Absorption	Ion Chromatography
Analysis Time	30 seconds	5-10 minutes per sample	2-5 minutes per element	15-30 minutes

Parameter	NIR Spectroscopy	ICP-OES	Atomic Absorption	Ion Chromatography
Sample Preparation	Minimal (grinding optional)	Acid digestion required	Acid digestion required	Water extraction
Cost per Analysis	$1-5	$25-50	$15-30	$20-40
Multi-element Capability	Yes (simultaneous)	Yes (simultaneous)	No (single element)	Limited
Accuracy (under ideal calibration and sampling conditions)	Moderate (R^2 0.80-0.95 majors) Poor (R^2 < 0.6-0.85 micros)	Excellent (R^2>0.99)	Excellent (R^2>0.99)	Very Good (R^2>0.95)
Detection Limits	Moderate (0.1-1.0%)	Excellent (ppm level)	Very Good (ppm level)	Good (10-100 ppm)
Equipment Cost	$15,000-50,000	$150,000-300,000	$25,000-75,000	$50,000-100,000
Portability	High (handheld available)	None (lab only)	Low (benchtop)	Low (benchtop)
Chemical Safety	None (no chemicals)	High risk (acids)	High risk (acids)	Low risk
Operator Training	Minimal	Extensive	Moderate	Moderate

Economic Considerations for Commercial Growers

The economics of NIR technology become compelling for operations analyzing more than 200 leaf samples annually. Traditional laboratory analysis costs typically range from 50 to 150 USD per sample including shipping and handling, while NIR analysis costs drop to 1 to 5 USD per sample after initial equipment investment. For a medium scale greenhouse operation testing weekly throughout the growing season, this represents potential savings of 10,000 to 30,000 USD annually.

However, the initial capital investment for quality NIR equipment ranges from 15,000 to 50,000 USD, depending on spectral range and measurement capabilities. Handheld devices suitable for basic macronutrient analysis start around 15,000 USD, while benchtop instruments capable of full spectrum analysis and micronutrient detection can exceed 50,000 USD (9).

Current Limitations and Future Prospects

Despite significant advances, NIR technology for leaf analysis still faces several limitations. Micronutrient detection remains challenging due to low concentrations and weak spectral signatures. Reliable calibrations for elements like iron, zinc, and manganese typically require concentrations above 100 mg/kg, limiting utility for detecting subtle deficiencies (10).

The development of machine learning approaches and artificial neural networks shows promise for improving prediction accuracy and handling complex spectral relationships. These advanced mathematical techniques can potentially extract more information from NIR spectra than traditional regression methods, particularly for challenging nutrients and mixed species applications. However the success of these techniques hinges on the amount of available data, if the learning library is not big enough, or your crop deviates substantially from it, your accuracy could be even worse than without these complex approaches.

Practical Recommendations

For commercial growers considering NIR technology, the decision should be based on sample volume, required accuracy, and available budget. Operations analyzing fewer than 100 samples annually are generally better served by traditional laboratory analysis. However, high throughput operations, research facilities, and precision agriculture applications can achieve significant benefits from a well calibrated NIR implementation.

When implementing NIR technology, invest in proper calibration development using samples from your specific crops and growing conditions. Generic calibrations provided by instrument manufacturers rarely achieve the accuracy needed for reliable nutrient management decisions. Plan for ongoing calibration maintenance and periodic validation against traditional analytical methods to ensure continued accuracy. **NIR instruments that cannot be properly calibrated for the exact conditions of the grower are much more likely to lead to unusable results.**

The future of leaf tissue analysis clearly points toward rapid, non destructive technologies like NIR spectroscopy. While current limitations prevent complete replacement of traditional methods, NIR devices offer valuable screening capabilities and real time insights that can significantly improve nutrient management efficiency under ideal conditions. As the technology continues to mature and costs decrease, adoption will likely accelerate across all scales of agricultural production.

Using Portable Low-Cost Chlorophyll Sensors to Assess Plant Health and Improve Crop

Quality in Hydroponics

When you grow plants hydroponically you become responsible for delivering the exact amount of every essential nutrient. Getting nitrogen right is particularly challenging since plants can require dramatically different amounts depending on their growth stage. Traditional methods to assess nitrogen status require sending leaf samples to a lab, which is expensive, destructive, and provides results too late to make timely corrections. Portable chlorophyll meters offer a practical solution.

A DIY chlorophyl meter compared to some commercial alternatives (taken from (9)).

What Are Portable Chlorophyll Meters?

Portable chlorophyll meters are handheld devices that non-destructively estimate the chlorophyll content in plant leaves. The most widely used device is the SPAD-502 meter, which works by measuring light transmission through a leaf at two wavelengths: 650 nm (red light, which chlorophyll absorbs) and 940 nm (infrared, which chlorophyll does not absorb). The device calculates a dimensionless SPAD value based on the transmission ratio (1). Since 50-70% of leaf nitrogen is contained in chlorophyll molecules, these readings provide a reliable proxy for nitrogen status (2).

These meters are particularly useful in hydroponic systems where you have complete control over nutrient delivery and can make rapid adjustments when deficiencies are detected. Research has demonstrated strong correlations between chlorophyll meter readings and nitrogen status in major hydroponic crops including tomato (3), lettuce (4), and greenhouse vegetables (5).

Major Advantages

The primary advantage is that measurements are instantaneous and non-destructive. You can measure the same leaf repeatedly throughout the growing season without harming the plant. This is especially valuable in hydroponics where you might want to monitor nitrogen status weekly or even daily during critical growth periods.

The correlation between SPAD readings and leaf nitrogen concentration is typically very strong. In romaine lettuce grown in soilless culture, SPAD readings showed correlation coefficients of $R^2 = 0.90$ with nitrogen concentration and $R^2 = 0.97$ with chlorophyll content (4). Similar results have been reported for greenhouse tomatoes, where R^2 values ranged from 0.86 to 0.94 (6).

Unlike laboratory analysis, chlorophyll meters provide immediate feedback. When you detect that SPAD readings are dropping below your target range, you can adjust your nutrient solution that same day, particularly advantageous in fertigation systems (7).

Low-Cost Alternatives

The SPAD-502 meter typically costs $2,000-$2,600, which can be prohibitive for small growers. Several low-cost alternatives have been developed and validated. The atLEAF meter costs around $200-$300 while providing equivalent performance (8). Studies found strong correlations (R^2 = 0.96) between SPAD and atLEAF meters across multiple crop species (8).

Functional chlorophyll meters can even be built from scratch using simple electronic components for under $100. A recent study described construction using 3D-printed hardware and off-the-shelf LEDs and photodiodes that achieved strong correlations with both the SPAD-502 and atLEAF meters (9).

Device	Cost (USD)	Wavelengths (nm)	Key Features
SPAD-502	2,000-2,600	650, 940	Industry standard
atLEAF+	200-300	660, 940	Data logging, SPAD conversion
MC-100	400-600	653, 931	Larger measurement area
Custom Arduino	<100	650, 940	Requires assembly

The atLEAF meter is available through agricultural supply retailers, while various manufacturers offer devices in the $100-$300 range through online platforms.

Research in Hydroponic Crops

Chlorophyll meters have been successfully used to guide nitrogen management in various hydroponic crops. In tomato production, using SPAD readings to trigger nitrogen applications resulted in the highest yields compared to fixedrate applications, with improved nitrogen use efficiency (3). Researchers established critical SPAD values for different physiological stages, allowing growers to apply nitrogen only when needed.

For lettuce grown in high tunnels with fertigation, both SPAD and atLEAF meters accurately estimated nitrogen status, fresh weight, and chlorophyll concentration with R^2 values above 0.90 (4). Research on basil with different nitrogen rates showed that SPAD, atLEAF, and MC-100 meters all provided reliable estimates with R^2 values of 0.93-0.98 (10).

Important Limitations

While valuable, chlorophyll meters have limitations growers need to understand. The relationship between SPAD readings and actual nitrogen content can vary between species. Research on seven crop species found that while the relationship between SPAD and chlorophyll content was consistent, the relationship between SPAD and leaf nitrogen varied widely (1). You cannot use the same threshold values across different crops.

Environmental factors also affect readings:

- **Time of day**: Chloroplast movement can cause SPAD readings to decrease by 13-28% at midday under low nitrogen conditions (1). Take readings in early morning or maintain consistent measurement times.
- **Light history**: Short-term changes in growth light affect nitrogen allocation to chlorophyll (1).
- **Leaf position and age**: Chlorophyll content varies across leaf positions and with age. Always measure the same leaf position.

Chlorophyll meters provide relative rather than absolute measurements. To use them effectively, you need to establish calibration curves for your specific crop and growing conditions.

Best Practices

Establish Baseline Values: Grow plants at different nitrogen levels and measure both SPAD readings and leaf nitrogen concentration via lab analysis. This establishes your calibration curve.

Use Reference Strips: Maintain a section of plants receiving optimal nitrogen. Compare readings from your bulk crop to these reference plants. If bulk readings drop more than 5-10% below reference, increase nitrogen delivery (7).

Standardize Protocol: Always measure the same leaf position. For leafy greens, measure the most recently fully expanded leaf. For tomatoes, measure leaflets on the leaf closest to the most recent fruit cluster. Take measurements at the same time daily, preferably early morning (5).

Take Multiple Readings: SPAD readings can vary 10-15% between individual plants. Measure at least 20-30 plants per zone and use the average (7).

Species-Specific Calibration: If you grow multiple crops, establish separate calibration curves for each.

Crop	Optimal Range	Action Threshold	Measurement Location
Lettuce	35-45	<32	Youngest fully expanded leaf
Tomato	45-55	<42	Leaflet near newest fruit cluster
Cucumber	40-50	<37	3rd fully expanded leaf
Basil	35-45	<32	Terminal leaves

Note: These are general guidelines. Establish specific thresholds for your cultivars through calibration with lab analysis.

Conclusions

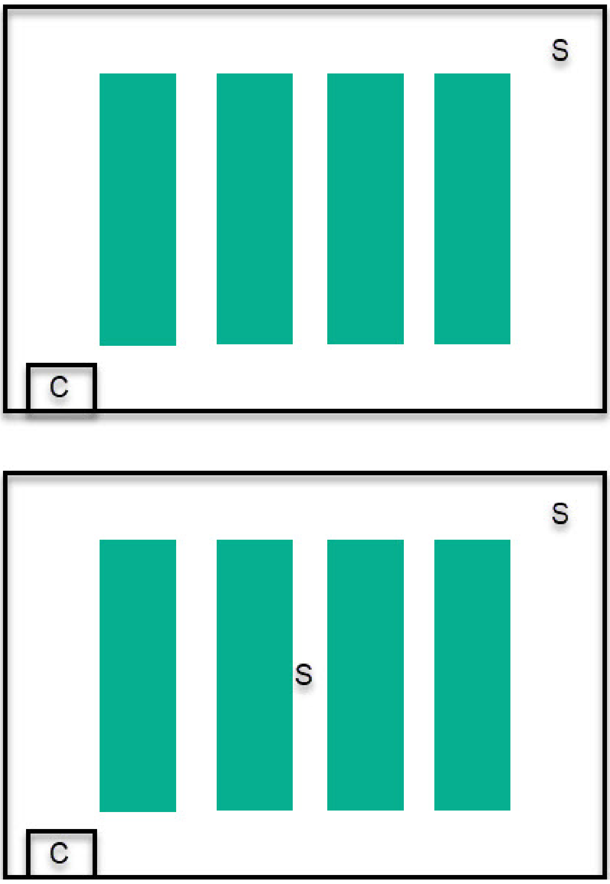
Portable chlorophyll meters represent an excellent investment for hydroponic growers optimizing nitrogen management. Low-cost alternatives make this technology accessible even for hobby growers. While these devices have limitations related to species-specific calibration and environmental factors, following standardized protocols allows effective use for management decisions.

The key is understanding that chlorophyll meters provide relative measurements. Take time to establish proper baseline values for your crops and conditions. Once calibrated, these devices help fine-tune nitrogen delivery, reduce fertilizer waste, prevent deficiencies, and improve crop yield and quality.

For growers ready to adopt this technology, starting with an atLEAF meter or similar low-cost device provides an affordable entry point with performance comparable to expensive options.

Properly positioning temperature and humidity sensors in a hydroponic growing environment

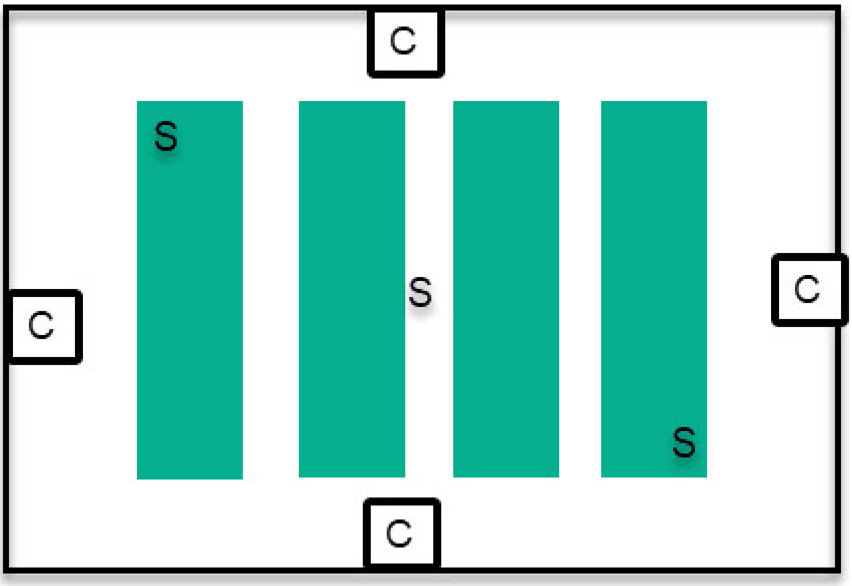
Temperature and humidity are two key variables you need to measure. They are important because they determine how your plants will transport water, and transpiration controls a lot of processes, with nutrient transport being one of the most important ones. However, the value of these variables in a growing environment – being that a greenhouse or a grow room – can change substantially depending on where they are measured. It is therefore critical to know where to place sensors and how to interpret their readings based on their location. In this post, we are going to discuss where it is best to measure these variables and what consequences it could have if these values are not measured properly.



Sensor placement relative to a control source (AC, humidifier/dehumidifier) for one or two sensors. Note that this setup assumes good circulation throughout the room, including middle of canopy.

Let's start with the worst possible case, you only have one set of sensors and you need to control your environment with it. *In this case, place your temperature and humidity sensors at canopy height, as far away as possible from both the AC ducts and the humidifier/dehumidifier, make sure the sensors* *are hanging in the air and not stuck to a wall or tubing*. Then, make sure you use a hot wire anemometer to verify that your air movement speed is at least 0.3m/s across the entire room. This setup ensures that the worst controlled part of the room is at the correct value and it also attempts to minimize the gradient created from the control sources to the sensor using a good amount of air circulation. It is not perfect though and significantly different "climate zones" will be created close to and far away from the climate control devices.

The above setup can be used effectively in small growing environments, but can be problematic as both the number of plants and the size of the growing environment increases. At this point, using a single set of sensors is not an option if adequate climate control is desired. In these cases, multiple sensors need to be placed to ensure that climate control is being done properly. When using multiple sensors, place the second sensor at the place with the lowest air circulation inside the room, at canopy height, which is usually in the middle of the room, then place subsequence sensors as far away from either this or the first sensor in sequence. When doing climate control, the system needs to ensure all of the sensors remain within a "safety band", making sure no sensor becomes too cold/hot, humid/dry, during control cycles.



Sensor placement for multiple control sources. Sensors are placed in order trying to always be as far away from sensors as possible but within the plant canopy.

When you implement a sensor system like this, you will realize pretty quickly that climate becomes very hard to control in a larger room when there is only one source of control (one AC, one humidifier, and one dehumidifier) because gradients become too big for effective control, so it takes too long for the AC to be able to properly control the room while ensuring all sensors remain within proper boundaries. In this case, it becomes necessary to add multiple sources of control, so that the extent of gradients within the room can be minimized. This means adding multiple ducts for the output of an AC, multiple humidifier/dehumidifiers, etc.

In these cases, sources of control are placed outside of the plant canopy to avoid plants being exposed to the flows from these control sources (which would expose them to very cold/hot/dry/humid air). Then the sensors need to be placed within the plant canopy, starting from as far away as possible from all sources of control – usually the middle of the canopy – and then to the corners of the growing environment.

Note that the control algorithm needs to ensure all of these sensors are within the proper control band and not attempt to control the average reading of these sensors. If you try to use the average of sensors to control a room, you might be left with a room where two extremes are present and the control system believes everything is ok while these extremes are maintained. The median is a better way to control a room, but it only becomes useful when 5 or more sensors are used. If only 2 or 3 sensors are used, ensuring all of these sensors are within adequate bands is fundamental to ensure that the room will have a lower chance of having humidity/temperature microclimates that will be detrimental to plant growth.

Commercial sensor and data logging solutions for hydroponics

On a previous post, I discussed a very interesting open-source sensor/data logging alternative for Hydroponics called MyCodo, which offers a lot of features and flexibility for those growers with the time and skills necessary to implement their own sensor and data logging setup. However, many growers don't have the time to do this on their own – or the time and willingness to hire someone to do it for them – and all they want is a solution that "just works" out of the box and that fits most of their data logging needs. In this post I am going to talk about three commercial solutions – in no particular order – that I've had experience with along with some of the advantages and disadvantages that each one offers you. **Note that this post has not been sponsored by any of these brands**. *The statements below represent my opinions on the matter and the facts, to the best of my knowledge. I recommend you* *contact each company to ask specific questions pertinent to your needs.*

Growtronix. This company offers a complete solution for monitoring and automation of hydroponic crops. Their sensors are hooked through cabled connections and they support a wide array of analogue sensors, both sold by them and by third parties. As long as a sensor can work on a 3.5-5V input and give an analogue reading, it can be installed in a growtronix setup. Their web interface is user-friendly, it allows you to view sensor readings and create control schemes using simple if logic statements. They have also shared the source code of their web interface with some of my customers in the past, so if you would like to customize things beyond their base web application, I'm sure you could figure it out if you have the time and programming skills. Growtronix support – per the experience of the customers I have you have used it – has been stellar.

There are however some downsides to using growtronix. Since everything is cabled you will need to lay cables across your rooms if you want to hook up multiple sensors within them. The system lacks support for third party i2c sensors, meaning that you can only connect analogue sensors and will miss on some interesting third-party sensor offerings. The data is also stored in a non-relational mongoDB implementation, which means that querying data and doing complicated data analysis will not be easy with them. Their control algorithm technology is also rather simple, to the best of my knowledge they do not offer more advanced control mechanisms beyond the if logic statements they allow the users to program.

Agrowtek. Similar to Growtronix, they also offer a complete monitoring and automation solution for hydroponic crops. However, they offer their own touchscreen computers to connect to their sensors, dosing pumps, and relay modules, so they do not have a dedicated web interface for their sensors that is hosted on any computer but you must purchase their own. Their "GrowControl" panels will hook with normal ethernet cables to any of the sensors they offer and you will be able to program all the behavior of the sensors and the relays from these stations. Their main advantage is easy setup, everything easily hooks up and you can then program things within the GrowControl panels to fit whatever simple control needs you might have. You can probably setup 200 sensors/relays in a day to control an entire facility using this setup. Their custom computer also gives you more stability, meaning crashes of the system are rare (according to the customers I have who have used them). From the three companies discussed in this post, this is also the only one to offer nutrient injection systems in their offering.

However, one big limitation of this company is how closed the ecosystem is. You have absolutely no ability to hook up third-party sensors and sadly their offering lacks some important and basic sensors for a medium to large scale hydroponic setup, specifically water content and water potential sensors. You are also becoming reliant on the availability of support from them and – if the company went under – it would be very hard for you to be able to fix or find replacements for their sensors or their control panels. Their control algorithms are also fairly simple and are limited to basic if-logic, similar to the Growtronix system. Data is also not logged into any database but as basic csv files, which means substantial effort will be needed to perform advanced data analysis tasks.

SmartBeeControllers. This company also offers a complete automation and monitoring solution for your hydroponic crop. Their main differentiating factor relative to the last two is that sensor stations connect wirelessly to your computer, allowing you to place sensors throughout your facility without having to set up cables through the entire place. Their sensor stations can hook up to a large number of sensors so, for example, you can use a water content station to hook up six of their capacitive water content sensors. They also require a computer server with the web software to communicate with – alike Growtronix – and their software has a focus on simplicity. In this case, control options are even more limited than in other cases, with basically only simple set-point logic available to control relays (to the best of my knowledge).

The SmartBee ecosystem is also quite limited and offers no pH/EC/ORP sensors or water potential sensors (tensiometers). You have no ability to hook up third-party sensors as well, meaning you're stuck with this offering if you use them. Because of the wireless nature of communications, sensor readings and their stability can also be compromised due to excessive electromagnetic noise, which can be particularly problematic in a short room that has a lot of HPS ballasts. It is also true that in the past (2-3 years ago) their support seemed to have problems, with several complaints about their response time online. I do not know if their technical support has improved so I would advise you to seek recent opinions about it on social media if you're considering them for purchase. The people I know who used them didn't need to contact support, so I cannot comment on this aspect from my customers' experience.

The above are three commercially available data logging systems for hydroponics. All of them should be easy to hook up and should provide you with basic data logging and control capabilities for your grow. In my opinion, the most complete one is Growtronix, given the ability to add third-party sensors – even if only analogue ones – and the quality of their sensors and web application software. However, if controlling the nutrient injection process electronically is important for your situation, then Agrowtek might be a better solution. None of them however provide advanced control mechanisms – like reinforcement learning-based climate control – and none of them provide access to all sensors that would be desirable, so a custom DIY setup might be best if these features are very important to you.

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

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

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

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

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

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

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

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

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

Optimal air speed in a hydroponic crop

Wind speed is a particularly important, yet often overlooked variable in hydroponic crops. While growers in greenhouses will pay close attention to overall gas exchange characteristics (how much air exits and enters a greenhouse) the speed of air around plant canopy is commonly not measured or optimized to maximize plant growth. In this post we will talk about why air speed is so important, why it needs to be measured around the canopy, and what you should be aiming to achieve within your hydroponic greenhouse or grow room.

Plants at higher wind speeds

The airflow around a plant will completely change the plant's environment. As air flows around the plant it will carry away oxygen and water and will replenish carbon dioxide. Besides this, the moving air will also dramatically increase heat transfer due to convection, effectively cooling the plant substantially (this is known as wind-chill) (1). Without any air movement, the plant will saturate the air immediately around it with oxygen and water and deplete it of carbon dioxide during the day, relying solely on diffusion across this depleted layer in order to get additional carbon dioxide. This will heavily limit the plant's ability to photosynthesize and will generally cause plants to be stunted and with a higher propensity for fungal/bacterial disease (since there is a very high relative humidity layer adjacent to the leaves).

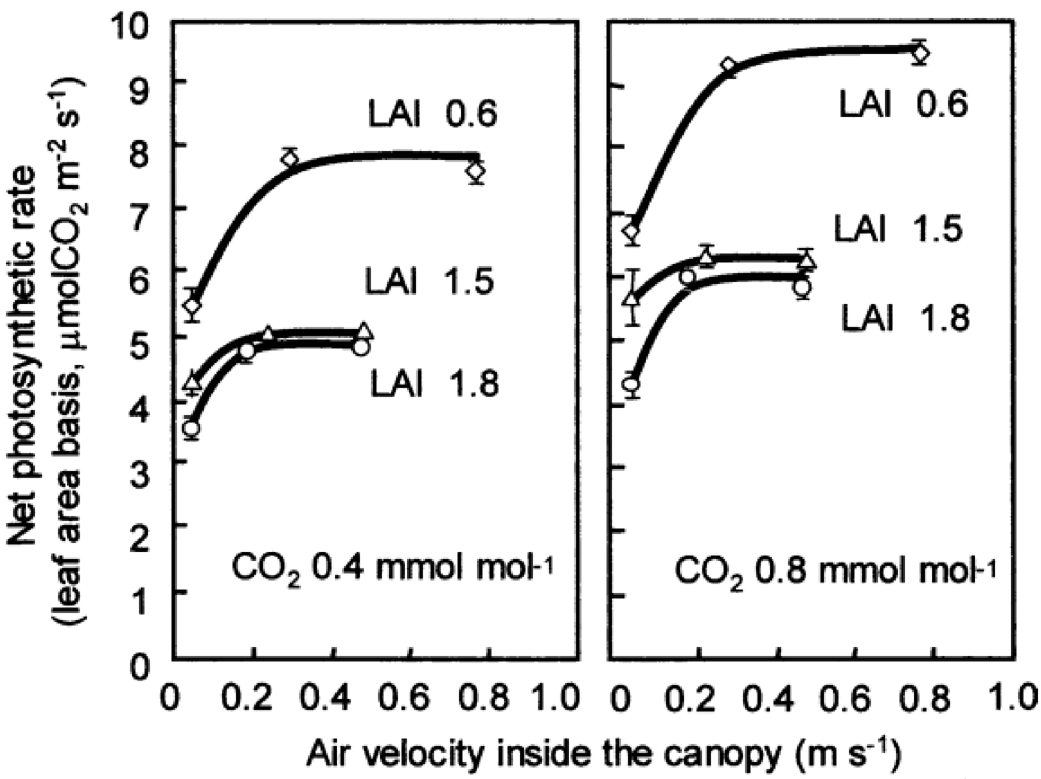
As airflow increases, so will the plant's metabolism. This will happen up to a point where the effects of wind chill or mechanical stress due to the air movement become too high. At low relative humidity values, high wind speeds will also pressure the plant to increase water transpiration substantially as the flowing dry air will strip the plant of humidity more efficiently. Due to this reason, optimal relative humidity will tend to be higher as airspeeds at the canopy increase. It is often quite common that to achieve optimal VPD – which often requires high humidity values at high temperatures – airspeed around plants needs to be increased to avoid fungal issues.

The airspeed around the canopy can be bad even if the in/out exchange characteristics of a room are optimal. This is because the flow of air into or out of a room says nothing about how the air is circulating through that room. Since air is a gas, it will go through paths of least resistance and will try to avoid the canopy – a very prominent obstacle – if it is allowed to. For this reason, intake/outtake structures that force air to go through the canopy and fan setups that direct air straight at the canopy structure are going to be significantly more effective at generating proper airflow. Since airspeeds around the canopy are going to be quite low (0-1m/s), it is not possible to measure these speeds accurately with regular fan-base anemometers, a hot wire anemometer will be required to make these readings. These devices will allow you to measure wind speeds that are quite low, with an accuracy of +/-0.1m/s.

A hot wire anemometer that can be used to accurately measure wind speeds around plant canopy

So what is the optimal airspeed you should be aiming for at plant canopy? The higher the airspeed, the higher your plant metabolism will tend to be and the more pressure the plant will feel to adapt to these environmental conditions. At some point, the plant is unable to benefit from increases in airspeeds due to the increased transpiration and wind-chill caused by the increased air-movement. The results of a study on tomato plants with different leaf area index (LAI) values in wind tunnels are shown below. As you can see, crops with lower LAI values will tend to do be photosynthetically more efficient, probably because these low LAI values are more adapted to higher airflow conditions. However, this does show that a limit to increases in photosynthetic rate based on airflow does exist.

To reach optimal photosynthetic rates, **the wind speed around the** canopy should be at least 0.3m/s, as this is around the point where flowering plants like tomatoes start reaching a plateau of photosynthetic production. Having a higher rate will provide little additional benefits under normal conditions, although aiming for 0.5-0.6m/s might provide a buffer to ensure that all regions of the canopy are above the critical 0.3/s threshold. Aim to have a homogeneous flow across the canopy in the entire room/greenhouse as you would have in a wind-tunnel. Higher airspeeds might be desirable if CO2 enrichment is being done, although care must be taken to ensure that the relative humidity is high enough to account for the additional wind chill that the plants are going to be subjected to. Also, aim to have these airflow conditions through the entire life of the plant, as early adaptations to the airflow regime will tend to limit what can be achieved by trying to increase airflow at a later time.



Photosynthetic rate as a function of windspeed, LAI stands for (Leaf Area Index). Taken from this article.

When possible, make sure you compare the LAI values of the different plants you have available. Low LAI values are going to be more suited to high density crops as their efficiency per leaf area unit will be significantly higher and it will be easier to maintain high airflow speeds within the canopy, while crops with high LAI values will make it more difficult for air to move through the canopy plus their photosynthetic efficiency per leaf area unit will be substantially lower.

Using VH400 sensors to build an automated irrigation setup

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

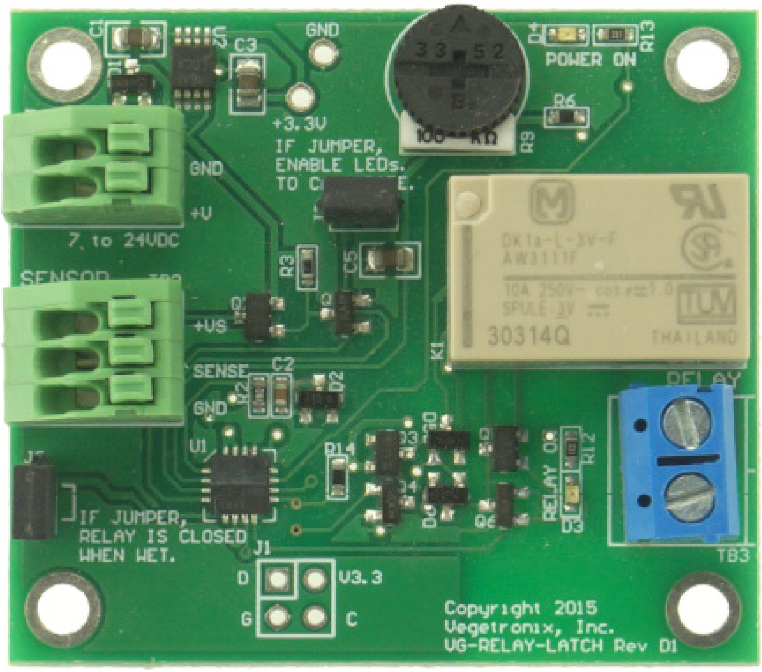
The VH400 moisture sensor

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

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

It is worth noting however that – although advertised as "unaffected by salinity" – it will require routine maintenance, washing with distilled water to reduce salt accumulation and recalibration to ensure it is giving accurate moisture content measurements. As with all moisture sensors, adequate calibration and monitoring of sensors is fundamental to long term success with them. I**f these sensors are not maintained they will stop giving proper readings with time**, especially if they are buried around the root zone of plants in hydroponic setups.

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



Vegetronix battery powered relay sensor

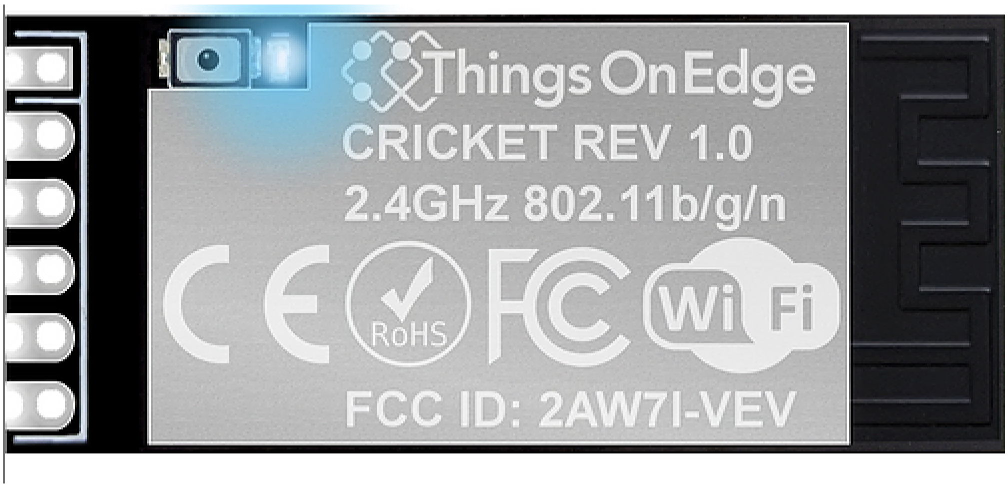
With the sensors in mind, we can now discuss the relay boards that make this choice quite attractive. The board shown above, which you can find here, is a battery-powered sensor that links to a single VH400 sensor to trigger a pump at a given moisture sensor threshold. All it takes to use this sensor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

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

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

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.

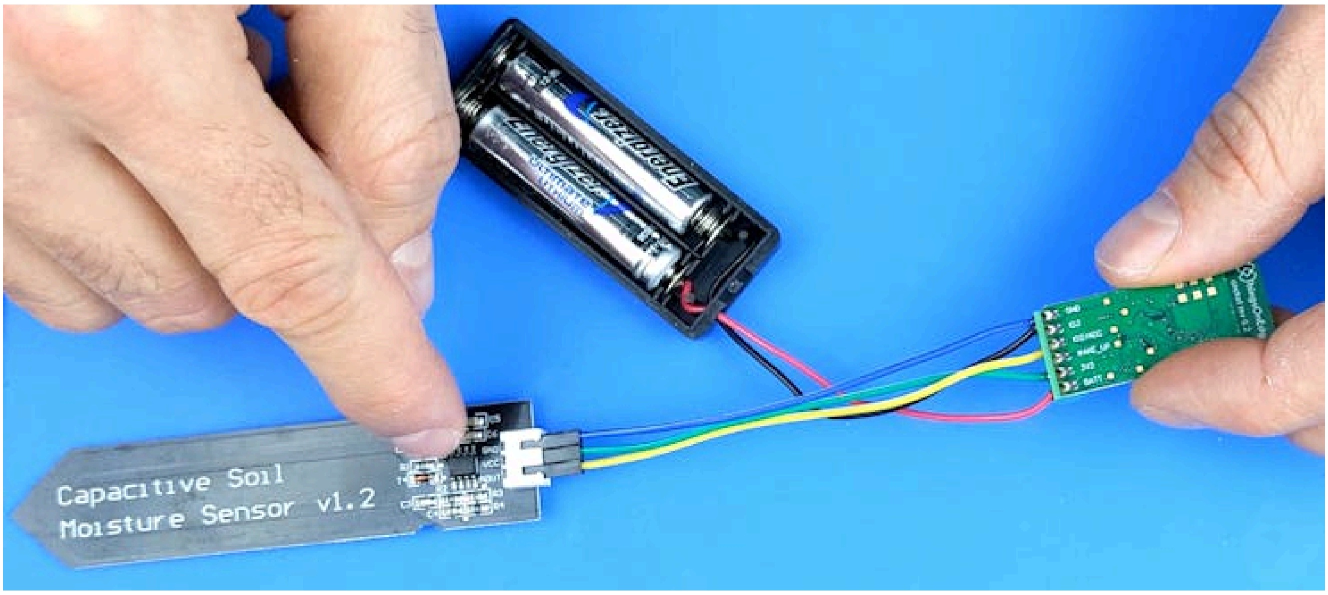


The cricket IoT board by ThingsOnEdge

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.**

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.

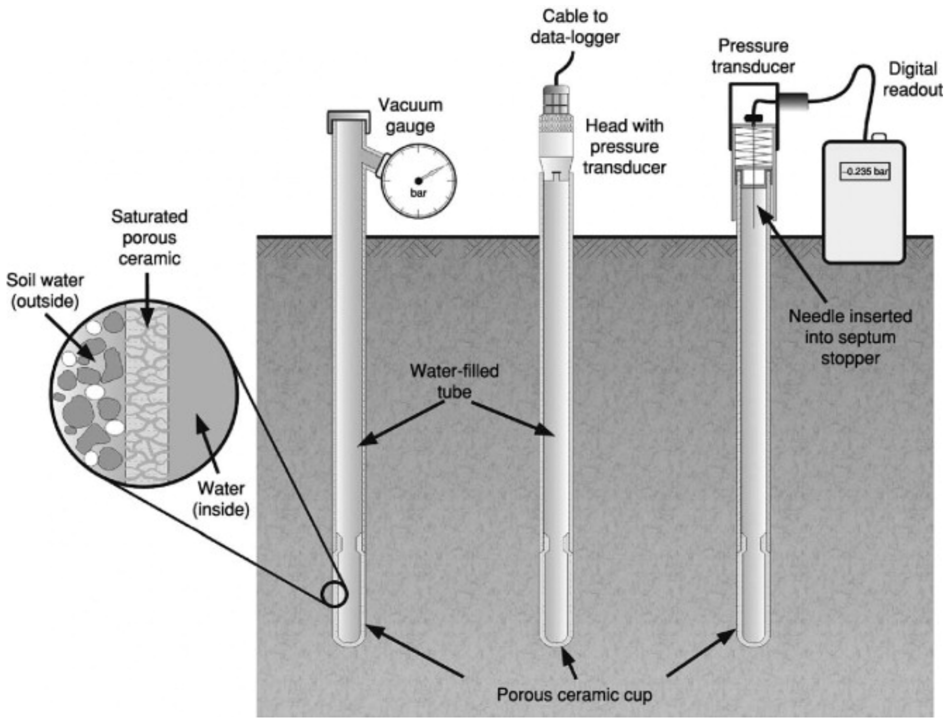
When an irrigation event is triggered it is also worth considering for how long this event will happen. If you water only till the sensor gives you a high moisture content reading, then there will be very little run-off and nutrients will tend to accumulate in the media and imbalances will be created 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.

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 first one was about the problems with resistive moisture sensors in hydroponics and the [second one] 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.

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 irrometer.com (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.