Measuring ion concentrations in hydroponics using electronic tongues

One of the biggest problems in hydroponic research is the measuring of individual ion levels in hydroponic solutions. Right now there is no commercial solution for the accurate tracking of individual ions in hydroponic solutions and this makes it impossible to track ions in real-time to measure how nutrient absorption reacts to different environmental and chemical conditions. The only way to currently do this is to carry out more expensive and cumbersome ICPE analysis that provides a snap shot of a solution's composition in time. However there is a solution that might be coming up within the next few years which is the use of electronic tongues to measure the concentration of a large variety of ions in solution.

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Many of you may be thinking, what about Ion Selective Electrodes (ISEs) ? These electrodes are designed to measure the concentration of individual ions in solution and they are perfect when you're trying to measure a single ion against an unchanging background. The issue with ISE is that they work via the interaction of ions with molecules that have a especially strong interaction with them (what we can an ionophore) but the interaction can also be strong with other ions, generating interference. For example a K+ ion selective electrode usually uses an ionophore like vancomycin but this ionophore also has strong interactions with NH4+ (ammonium)

ions. Since the concentration of ammonium also changes with time in hydroponics this means that your reading will be changed not only by how K+ concentration varies in solution but also by how NH4+ concentration changes.

In reality interference is not generated by a single ion but by a good portion of the ions present in a hydroponic solution. This means that it is practically impossible to use an ISE in an accurate manner in hydroponics because you will always be getting changing interference from the other ions in solution. In the experiments I have done attempting to track nutrients using ISE this problem has always been so bad that the results become practically useless, regardless of how you calibrate the electrodes (since the concentration of the ions that interfere changes relative to the ion you want to monitor).

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Electronic tongues are an intelligent idea to circumvent these problems. The idea is to use many ISE for different ions – with many for the same ion and many generic ionophores that have poor selectivity – and then to use statistical modeling tools – mainly neural networks – to come up with ways to figure out the noise/signal/interference and get accurate measurements for ion concentrations regardless of what the actual readings of the electrodes are. The neural network is trained with data from solutions with varying concentrations of all the ions being monitored and this allows the creation of a robust prediction engine that can be used to get actual ion concentrations. M. del Valle's group in Barcelona has done some of the pioneering work in this area, the images in this post have been taken from some of their research papers on the subject (for example this one and this one).

Through this research they have been able to come up with ISE arrays that – using the neural network models – can measure concentrations in real-time for nitrate, chloride, sodium, potassium, ammonium, calcium, magnesium and phosphate. This means that you can effectively monitor how plants absorb different ions, not only allowing you to carry out experiments surrounding nutrient absorption but also allowing you to know which ions are getting depleted so that you can replace them. This brings a totally new dimension into hydroponic culture that simply isn't accessible right now.

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It might take a significant time for these sensors to reach commercial applications – mainly due to the expensive calibration that is needed due to the variability in fabrication – so it might be years before we see something like this available to the general public. However if you have a commercial hydroponic setup that is large enough you definitely can follow this research to make your own ISE array and build an electronic tongue with them. This will give you access to a ton of information that is inaccessible to all of your competition.

Automated media moisture monitoring in hydroponic

crops

Irrigation control is one of the most important things to control in a hydroponic crop. Irrigate too frequently with a media that has high water retention and your plants will start to wilt as their roots die due to lack of oxygen and reductive conditions, water too sparingly and your plants will not grow as much as they could and maybe even die from the drought conditions you're imposing on them. On today's post we will discuss the topic of irrigation, more importantly how to know when to water your crops and how to control this process using sensor based approaches instead of just using look-and-feel to determine when to water your plants.

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Plant roots need to have access to water and nutrients. This means that the root zone needs to be saturated with nutrient-rich water as often as possible while avoiding oxygen depletion and salt accumulation. This means that irrigation needs to be controlled to ensure that plants get as much as possible, as often as possible, without going into any excess that would be detrimental to growth. Sadly there is no solution that is true for all crop setups and gauging irrigation frequency requires a close monitoring of what is going on within the crop.

To really know when to irrigate crops you should have a way to properly monitor moisture levels. This can be achieved through several methods, for example with tensiometers or with simple weighting of the plants, but many of these methods are often not cheap or practical for routine practice. Manual inspection of plants can also be misleading

since top level moisture perception is subjective and can often lead to very suboptimal results.

In today's world the best way to monitor moisture without having to pay a high cost is to use simple capacitive moisture measuring sensors. These sensors are corrosion resistant and independent of salt concentrations in solution and therefore provide you with a good measure of moisture within your root zones without having to worry about the conductivity of the nutrient solutions. My favorites right now are this small capacitive sensor for smaller media containers and the chirp for larger containers. If you don't want the chirp features and just want sensor readings you can also get this simpler I2C sensor for larger containers. Both of these sensors are cheap and can be installed in crops with many plants.

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If you want to go with the simplest possible setup the chirp provides auditory signals when plants need to be watered, although this is not the ideal way to setup the sensors. Ideally you would want to connect these sensors to an arduino so that you can process the data. The arduino mega is particularly well suited for this task as you can connect up to 16 analogue input sensors to it, however you

can use less analogue inputs with a normal arduino. Both sensors provide sample code for measuring values from an arduino, you can then output them to an LCD screen or save them within a computer. You can even connect the arduino's digital outputs to a relay so that you can automatically trigger your irrigation system when a custom set moisture level is reached.

Obviously you do not have to place a sensor within each plant. Just monitoring around 10-20% of your crop will give you enough information to know exactly how moisture levels behave within your crop and when you should ideally water them. This will eliminate all the guessing from your watering and will allow you to water your media perfectly while completely accounting for how long it takes for water to leave your plants. This means you no longer would need to just guess when to water, but your watering will be perfectly tailored to what your media allows and what your plants need.

Automating a hydroponic system: Sensors and monitoring

Hydroponic systems benefit greatly from gathering more information as this gives the grower the ability to better diagnose problems and better understand the evolution of their hydroponic crops. Usually growers limit the information they gather to single sensor measurements carried out either at different points during the day or even only when nutrient solutions need to be changed. These measurements are often not

recorded and are difficult to analyse in a wider context. Today I am going to talk about the automation of sensors in a hydroponic crop and the benefits this can yield you in the longer term. I will give you some advice regarding how to do this and will in a later post provide some practical steps to achieve an automatically monitored setup. Below you can see a picture of the output of my home hydroponic setup monitoring pH, EC, ORP, humidity, ambient and solution temperatures.

Automating sensors is not only having sensors that can take readings at predefined intervals but also making sure that the reading from these sensors are stored so that they can be used for analysis and diagnosis later on. Thankfully these days we have Arduino micro-controllers which are compatible with a wide variety of sensors that can be used for automated monitoring. We also have very cheap raspberry pi computers which we can use to store this information and build a database with our sensor information. Ideally we would like to monitor as many variables as possible but we are somewhat limited both by cost and the sensor capabilities of the Arduino micro-controllers. If you want to perform automated monitoring then you would definitely want to buy pH, EC, ambient temperature, solution temperature, humidity and carbon dioxide sensors. If you have more money or want to have more data then I would also advice getting a dissolved oxygen sensor and an ORP sensor. If you have a large grow room then you might want to place several CO2 and temperature sensors to properly monitor the entire crop. Here is a small shopping list with sensors and micro-controllers you could use for this:

- Temperature and humidity sensor 5.20 USD
- Arduino UNO 23.90 USD
- Raspberry Pi 39.95 USD
- ORP sensor 89.05 USD
- pH sensor 56.95
- EC sensor 69.90 USD

- Arduino LCD shield 24.95 USD
- Dissolved Oxygen 257.45 USD
- Real-time clock module 13.55 USD
- CO2 sensor 56 USD

Although the LCD shield isn't really necessary for the setup it does allow you to write an Arduino program that displays readings right away. This is very useful as you can see readings as they happen within your hydroponic crop. The image below shows you how this looks like within my home hydroponic setup. In this setup I have all the sensors constantly taking measurements from the crop, which are displayed in this LCD screen. There is also a raspberry pi connected to this Arduino that records one measurement every 2 minutes. I don't record measurements any faster since this would cause the memory usage to grow very fast within the Raspberry pi without any important gains in the amount of knowledge gained from the information taken.

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It is also important to know that the sensors should be industrial quality sensors designed to be kept submerged all the time. For example the above ORP, dissolved oxygen and EC meters are not designed for being constantly submerged so after a while they will stop working and you will need to change them. However if you clean the sensors around once a week and cover the body of the sensor – especially where the cable goes out the back – with electrical tape you can significantly extend their service life. After they run out you can still use the interface to connect an industrial grade sensor. It is worth noting that all sensors can lose their calibration so you want to calibrate your pH/EC sensors at least once every month within this setup. Also when taking

sensor measurements you will want to take the median of a large number of measurements (>100) in order to ensure better stability.

Within a followup post I will share the code I use for my automated home setup as well as some additional information dealing with the automatic use of peristaltic pumps to automatically adjust pH/EC and ORP. For a few hundred dollars automated monitoring can greatly increase your ability to understand your hydroponic crops.