Using biochar in hydroponics to improve yields

The media used in hydroponic crops can vary widely around the world depending on what’s cheaper and more easily available in large quantities. In the United States, coco coir, peat moss and perlite tend to be favored while other regions might prefer media like rice husk, sand or vermiculite. However there is an entire type of media that is available in significant quantities almost any place where plants are grown, that is rarely used: biochars. These are produced from the controlled burning of plant materials and offer a myriad of potential benefits not commonly available with the other media types. Furthermore, biochar – combined with other media – can actually provide significantly better results in hydroponic culture. In this post I’ll talk about biochars, their properties and walk you through some of the evidence showing how they can substantially improve yields.

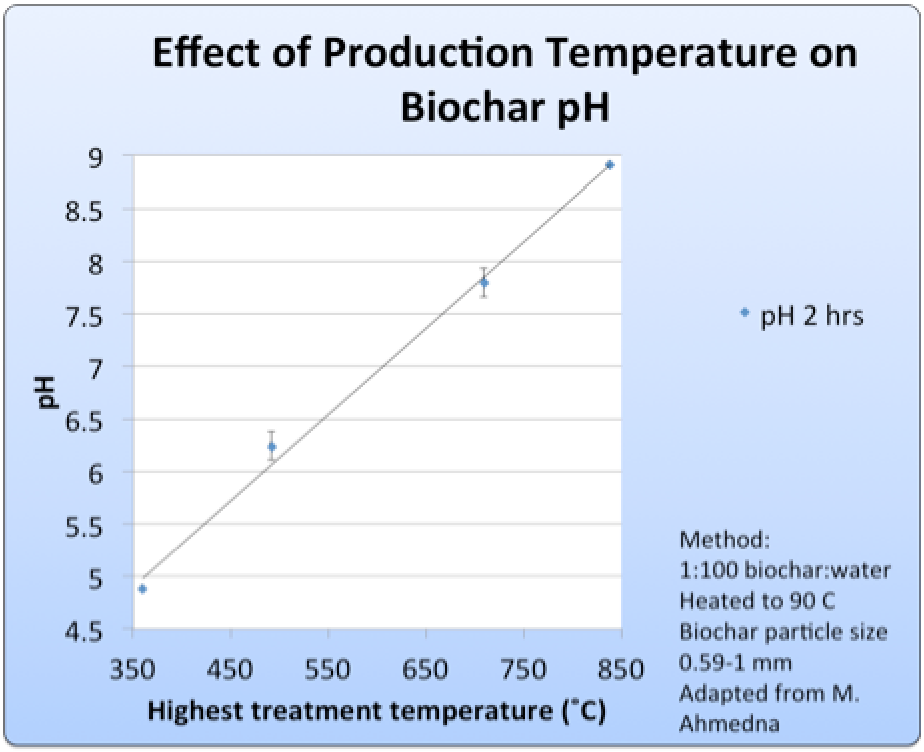
Biochar material generated from a previous crop cycle

First let’s talk about the properties of biochars. Since they are the result of burning plant material, their chemical and physical properties will be inherited from the parent plant material and the nature of the burning process (temperature, speed, oxygen availability, etc). The table below shows the properties of biochars from 3 different plant sources coming from the exact same process. Although all of the biochars are basic, their cation exchance capacity (CEC) and EC values can vary very substantially. The CEC is substantially lower than that of a media like coco coir (which can be in the 40-60 range in terms of cmol/kg) but the density of the media is much higher with biochar around 80-320kg/m^3 while coir is way less dense at only 80-100 kg/m^3. This means that the volumetric exchange capacity of biochar is around the same as coir but can be much larger depending on the specific source of biochar. **Note that the initial pH of biochar can vary very widely, from around 5 to 10, depending on the temperature used to make the biochar** (see second image below). These two tables show you how the properties can vary both due to the process and the plant material used.

Properties	CS[a]	SG	PW
Specific surface area ($m^2 g^{-1}$)	176	188	233
pH	10	10.8	9.3
EC ($\mu S cm^{-1}$)	800	550	120
Ash content ($g kg^{-1}$)	459	458	397
CEC ($Cmol_c kg^{-1}$)	24	19	9
Total C ($g kg^{-1}$)	480	495	550
Total N ($g kg^{-1}$)	4.1	4.5	3.3
Total P ($g kg^{-1}$)	1.9	2.1	0.4
C/N	176	188	233

[a] CS, corn stover biochar; PW, pinewood biochar; SG, switchgrass biochar; EC, electrical conductivity; CEC, cation exchange capacity; C, carbon; N, nitrogen; P, phosphorous. Biochar characteristics adapted from Chintala et al. (2014).

The table above was taken from this article (https://www.ncbi.nlm.nih.gov/pubmed/28618279)



This image was taken from here (https://langara.ca/departments/chemistry/biochar-project/production-and-characterization-of-biochar.html)

Biochar is not commonly used by itself but as an amendment to improve the properties of other media. Evidence across several different plant studies shows that biochar amendments systemically increase the yields in hydroponic crops. The first image below – taken from a study on cherry tomatoes – shows how a 5% amendment of biochar in coco peat was able to significantly increase the diameter of fruits produced. The second image – from a study on peppers – shows how the addition of the same 5% amendment of a "nutrient poor" biochar in coco coir produced very substantial increases in biomass over controls. There are several other studies that show improvements due to the use of biochar amendments, either under normal or stressed conditions (2, 3, 4, 5, 6, 7). From the evidence it seems to be clear that biochars can provide substantial benefits to hydroponic crop production. This is further cemented in this review about the use of biochar in container plants, which goes into additional evidence about the matter (plus some problems I'll also address later in this article).

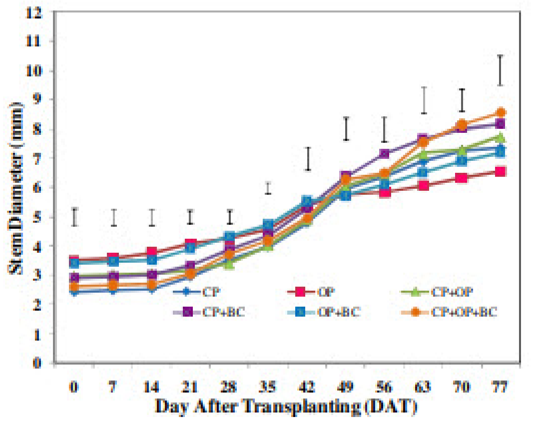


Figure 1. Effect of different soilless growing media on stem diameter of cherry tomato. Vertical bars represent LSD (P≤0.05)

Image taken from [this article]

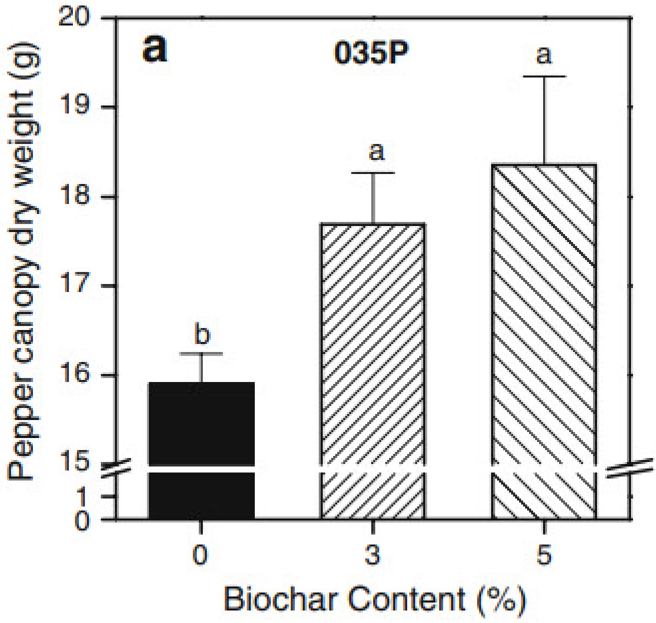


Image above taken from [this study] on peppers

But why does biochar work? There are currently three hypothesis that could explain the benefits available from biochar. The first is that it has a higher affinity for plant root exudates and other toxic substances that harm plant growth. By removing these substances, the biochar that is within the media ensures that the roots are always in a less toxic environment. The second hypothesis is that biochar provides a more welcoming environment for beneficial microbes, because of its chemical nature and pore structure, that facilitates the creation of beneficial symbioses that are harder to maintain in other media. The third is that the biochar has higher affinity for some nutrients, particularly nitrogen, enabling the plants to maintain a steadier supply of nutrients between irrigation cycles (this chemical behavior is well documented, see here). Potentially getting these three benefits makes biochar one of the most obvious improvements to hydroponic crops. **A potential 20%+ improvement in yields could be realized in this case**, if results from the literature translate into your crop.

However there are also problems with the use of biochar in hydroponics that should not be overlooked. In particular there is the problem of consistency and quality of chemical and physical properties. Since biochar properties depend so much on the creation process and sourcing material, it is quite easy to get a biochar that is detrimental instead of beneficial to plant growth. The second problem is the potential availability of toxic substances within the biochar that might harm your plants or make your products heavily toxic. Biochar source materials can be contaminated with heavy metals and toxic organic compounds can be generated within the high temperature process. It is therefore vital to ensure that the biochar you use contains neither of these issues.

Ensuring that the EC, pH , CEC and mineral properties of the biochar are aligned with the ones that provide the most benefit in the literature is a good place to start but ongoing quality controls are also necessary to ensure that the supplier has not changed the source or chemical process in a way that's detrimental. Producing your own biochar – since the equipment to do so is fairly simple – can also be a good possibility, given that a lot of plant material can also be wasted in crop cycles and this material could then be recycled as media for the next crop.

Six things to consider when running experiments in hydroponics

Two different growing facilities are never exactly the same. Fine tuning nutrient solutions, irrigation cycles and environmental conditions is therefore fundamental to achieve the best possible outcomes under different growing conditions. This naturally requires experimentation, which is not trivial to carry out. Today I am going to talk about five important things you need to consider when carrying out experiments that will help you maximize what you learn from them and avoid running experiments where no valuable information will be obtained.

The number of plants. Any experiment relies heavily on sample size in order to generate data that can lead to valid conclusions. A small sample size will have an inherently larger variability due to randomness that will make any conclusions naturally weaker. The smaller the studied effect is expected to be, the larger the sample size that will be required. Some things can be studied with a small number of samples – say just 5 plants – while others require very large number (+100 plants). For example if I'm trying to determine whether a 5000ppm concentration of Na will kill plants I can just do that with a small group, while if I'm trying to determine the effect of several different levels of Na on plant growth, then I'll need a large group, properly divided among different treatments.

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The number of variations. Related with the above, the success of an experiment also depends on what we're changing and by how much. The simplest form of experimentation (A/B testing) tries to determine whether there is a difference when changing one single thing from one state to another but this form of experimentation can be heavily impractical since we want to get as much information as possible per crop cycle per plant available for experimentation. This means we need to design experiments where several variations are tried yet statistically relevant conclusions can be reached. If you don't know how to do this, A/B testing is a safe bet, but it will take you longer to gain information.

Always have a control. Whenever you run an experiment, an adequate control must always exist. There must always be a hydroponic crop that is run side-by-side the experiments you're running in which the variables you're experimenting on are not being touched. A control needs to always be present – a result in the past cannot be used as a control – since the control must experiment all random influences that the plants that you're currently experimenting on are facing.

Collect as much data as you can. Plants do not grow fast, so experiments are extremely valuable and their data should not be wasted. Whenever you're running an experiment make sure you measure all possible outputs that might be of interest. You want to measure time to maturity, yields by weight, shoot weight, root weight, yield quality, leaf area, leaf composition, etc. Any variable that might be of importance to the success of your crop should be measured, because otherwise you're wasting information you already have and obtained through your experimentation. I cannot tell you how many times I've seen people regret not having measured everything they could when they carried out expensive or long experiments.

Control (left) vs variation (right) for an experiment testing the effects of Cadmium in plant morphology

Be careful about differences with controls. The only difference between your control and your experiment should be the variable(s) you want to study. If something else is different then it will be a confounding variable for your study and you might wrongfully assign an effect to a variable while the real effect came from something completely different. A classic problem is a localized difference in VPD caused by differences in air-circulation between locations. A plant under a higher VPD will show things like higher Ca in tissue, which you might mistake as being caused by the variable under study.

Blind experimentation is VERY important. Ideally the people carrying a study should be double-blind to it. If you're measuring the effect of potassium in solution and you're running a set of plants under 200ppm and another with 400 ppm, then the person preparing the solutions should not know which tank feeds which set of plants and the person measuring the yields and the plant weights should not know either. Only in the end – after all data is collected and the experiment is executed – should the true nature of what went where be revealed. Blindness is extremely important because otherwise people might introduce biases into the study, for example the grower might be predisposed to thinking that higher K is better, so he will care more for those plants because of confirmation bias. *These effects can be dramatic, we should care about blindness specially because of all the ways that not being blind can ruin a study that we cannot think of!*

The above is only a short list of things I consider important to take into account when carrying out experiments with plants. It’s certainly not an exhaustive or advanced list – just a list of basic pointers – but I believe these can be extremely useful for anyone trying to improve their current hydroponic crops or anyone currently carrying their own hydroponic experiments.

Why you should optimize your nutrient solution for your particular setup

In hydroponics, most plant nourishment is delivered through the use of a nutrient solution. This solution is prepared from raw fertilizer inputs by the grower – or a fertilizer company – and should contain adequate mineral ratios to maximize plant growth. However, although basic solutions can successfully grow crops under a wide variety of conditions, large increases in yields are possible with the optimization of the nutrient solution for each particular setup. Today’s article talks about why this is important and why a one-size-fits-all solution simply does not exist in hydroponic culture.

A nutrient solution is, generally, a very complicated mixture of different substances. All solutions should contain all mineral elements that are necessary for plant growth, which means that every solution contains at least 13 variables that a grower can change in order to improve their crop yields. You may think that every plant species has a magic set of variables that provide the best results but – in reality – this does not happen because plant/nutrient dynamics depend on the growing environment as well.

Since nutrients in solution are absorbed through plant roots, the root environment plays a huge role in determining how nutrients get absorbed by plants. The root environment depends on the media being used, the temperature and the way that water cycles in and out of the media. Nutrients are not absorbed in the same manner in a crop where watering is done once every 12 hours compared with a crop where constant dripping over the media is maintained. The nutrient solution also interacts with the media with time and different things can buildup depending on the frequency of the waterings, how well oxygenated the nutrient solution is and how the nutrient solution interacts with the specific media being used.

The outside environment also plays a huge role, due to the way that mineral transport is tied to water transport within plants. An environment with a high vapor pressure deficit will increase water transport through the plant, which will significantly increase Ca transport, while a higher moisture environment will hinder Ca transport and increase the transport of other minerals. The amount of air movement around the canopy, the concentration of carbon dioxide and the amount of temperature variation also play a huge role in determining what nutrient ratios will work best for a particular growing setup.

Sadly, no two growers ever have the exact same root and outside environment conditions. The optimal solution for a grower using coco coir in a high VPD environment will be very different from the solution used by someone using rockwool under low VPD, even if both people are growing the exact same plant. For this reason, performing a proper optimization of the nutrient solution is fundamental to increase nutrient usage efficiency and maximize growth. I will write more about how this is done in practice next week.

If you would like to know more about how this can be done in practice in your commercial hydroponic crop, please do not hesitate to send me an email, using the contact form on this page.

Five common reason why you're losing yields

Mistakes in hydroponic culture are not uncommon among both amateur and seasoned growers. Since there is considerable distances between a successful crop and an optimal crop, growers can go a long time without noticing mistakes that are likely to be heavily detrimental to their actual crop yields. Today I am going to share with you five of the most common problems I see when consulting for hydroponic growers and why these might be costing you a lot in yields.

Sup-optimal vapor pressure deficit. Temperature and humidity play a huge role in guaranteeing a large crop production. Plants can survive under a wide array of environmental conditions but the range where they produce optimal results is dependent on several factors, including the amount of carbon dioxide in the air, the plant species and the nutrient solution used. Most growers who make mistakes regarding VPD are either growing at a temperature that's too high or at a humidity that's too low. During winter low humidity tends to be the largest problem while during the summer issues with higher temperatures are most common.

Bad environments around root zones. Many growers water their plants with nutrient solution without measuring the characteristics of the solution that comes out of their media. Not measuring run-off EC/pH, especially when using non-recirculating setups, is a recipe for failure since the grower is completely unaware of whether root-zone conditions are good or not. More often than not, growers who make this mistake end up with very high salinity and extreme pH values – often acidic – that can be extremely hard to correct.

No foliar spraying regimes. Plants can take a lot of nutrition through their root zones but certain additives and nutrients are taken with far more efficiency through leaves. A lot of yield can be gained if proper foliar spraying with adequate additives to enhance growth is carried out. Many growers do not carry out any foliar spraying, leaving a lot of potential growth on the table that could be gained with these procedures.

No silicate applications. Potassium silicate is a very important additive in hydroponic culture and can make the difference between a very successful crop and a crop that has been heavily affected by fungal or bacterial diseases. Silicate applications have been repeatedly demonstrated to make plants immune systems stronger and – through the prevention of diseases and the strengthening of plants – can lead to healthier plants that have stronger yields.

No tailor-made nutrient optimization. Each particular grower has a specific set of plant species, varieties, media, temperature/humidity and carbon dioxide conditions that make their particular growing situation unique. Although generic nutrient solutions can do the job well enough to provide satisfactory yields, there is a lot of potential product left on the table if proper optimization of the nutrient solution is not carried out. Some nutrients – like phosphorous and calcium – benefit greatly form being optimized to the particular conditions each hydroponic grower has. Optimization takes effort and money – as some plants need to be dedicated to research – but the results can be more than worth it.

Although the above is not an exhaustive list of potential problems, it does provide you with an idea of the things that you might be doing wrong. With this in mind you can start to do your own research to attempt to fix these issues or you can contact me and schedule a call directly so that I can help you improve your hydroponic growing results.

High P or low P? The mystery of phosphorus in hydroponic culture

If you searched for the optimal P concentration for plant growth in hydroponics you will likely find very different results, ranging from low values to very high values. This is inherently contradictory and difficult to understand, why don’t we have a smaller range for optimal P conditions? Why has it been so hard to describe what the best P levels are? Today we will talk about P nutrition and why there has been so much confusion regarding optimal P levels in hydroponic culture.

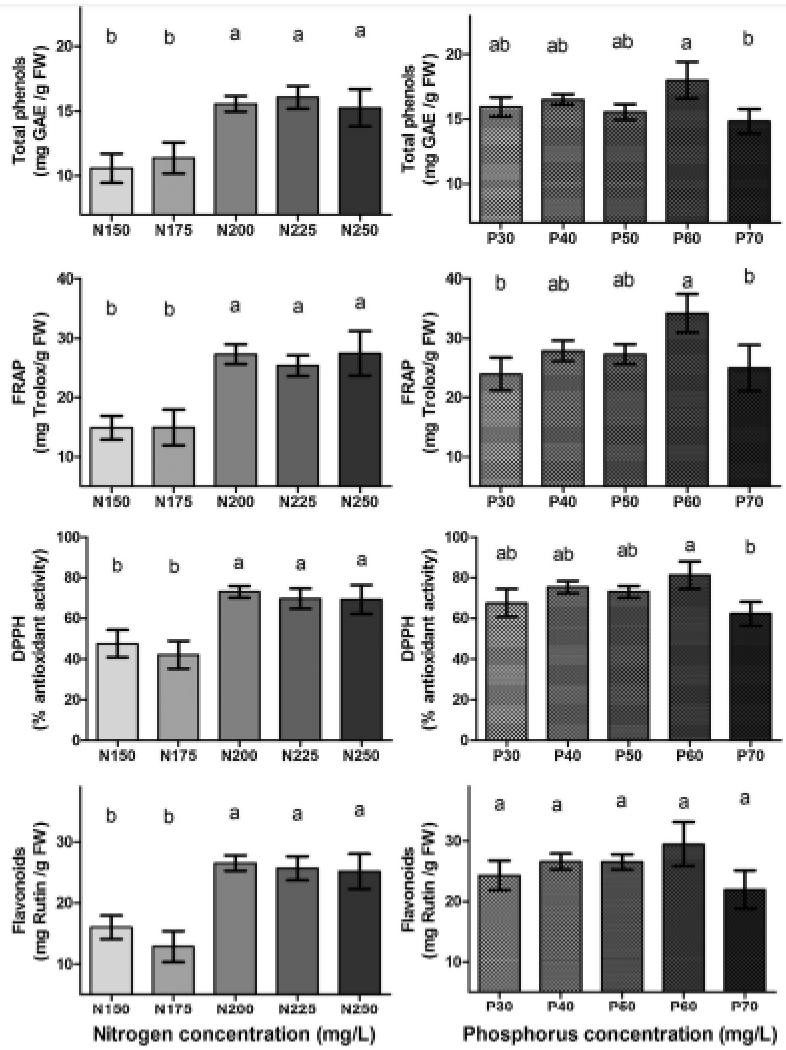


Fig. 1. Effects of nitrogen (N) and phosphorous (P) concentrations on total phenol mg GAE/g fresh weight. antioxidant activity (DPPH, FRAP, in mg Trolox/g fresh weight) and flavonoids (mg Rutin/g fresh weight) of lavender plants grown hydroponically in perlite.

Effects of P and N concentration on lavender plants (taken from this article)

Almost all books about hydroponics and flowering plants will put optimal P concentrations in solution between 20 and 50 ppm, rarely will you find any book recommending P levels outside of these values in general, since these are recognized to be safe and they play well with standard nutrient concentrations used for other elements. However you will find articles for different plants recommending P levels that can be as high as 200 ppm to as low as 10 ppm. Take for example this article on Calendula, which recommend a P application of 10ppm, while this article on Lavender suggests 60ppm. Note that optimal P might also depend on the desired result as this article on *Origanum dictamnus* shows that there is a movements of essential oils from leaves to bracts at higher P concentrations in these plants.

Not only is there confusion about optimal P levels, but even the effects of P and the interaction of P with micronutrients are not very well understood. There is evidence (see here) that P promotes Mn uptake in tomatoes while it suppresses Fe and Zn uptake, while we have entirely different results in barley, where P is found to actually impede manganese acquisition. The above two articles also give a lot of references to P uptake literature, which I suggest you checkout if you would like to learn more.

Table 1. Yield % (v/w) of the Essential Oils of Leaves and Bracts of Cultivated *Origanum dictamnus*

phosphorus concentration mg/L	leaves	bracts
5	3.1	3.8
30	2.7	4.0
60	2.8	4.3

Table taken from this article

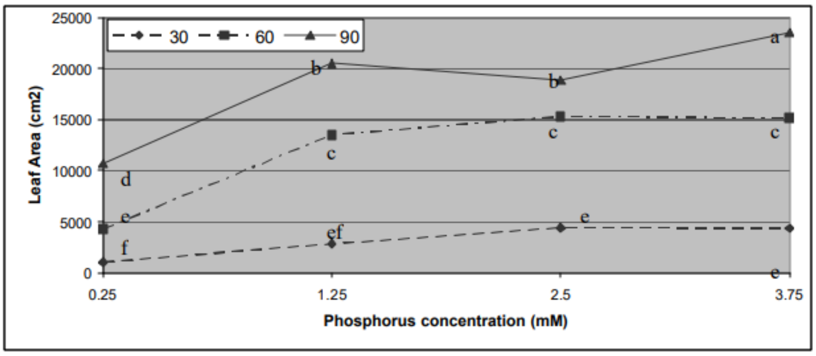


Figure 3.1 Effect of phosphorus concentration on leaf area of tabasco pepper plants grown in hydroponic greenhouse culture at 30, 60, and 90 DAT. Observations with the same letter are not significantly different, means separation by Tukey Kramer method ($P<0.05$).

Taken from this thesis.

The P literature is quite extensive (I suggest you read this thesis and its references if you would like to get a deeper dive), but overall we know that concentrations below 20ppm are rarely optimal and we do know that levels above 60ppm can be optimal for some plants under some conditions. In the thesis mentioned above we can see that tabasco pepper plants have the highest leaf area after 90 days in a P solution at almost 120 ppm.

Optimal P levels are perhaps harder to evaluate because they depend substantially on the concentration of other elements in solution as well as solution pH and root zone temperatures. We know that lower P stimulates root growth and reduces shoot growth while higher P levels have the exact opposite effect. Therefore variations in the ratio of P to other nutrients might be the optimal path for many crops but this is very hard to generalize as it depends on the particular growing conditions of each particular crop being grown.

Sadly the answer is that we don't have an "optimal P" that will match all growing conditions and plants. We know that growing with a P value between 30-50ppm will give you decent results on almost all crops, but we also know that there are substantial gains to be made by optimizing P under your particular growing conditions (plant, media, tempeatures, etc). In some cases 50%+ increases in yields might be possible if P is properly tuned to the exact growing conditions used.

Your optimal P might be way lower or higher than what's recommended in the literature, so start with the ballpark literature recommendation and make experiments from there to properly adjust P to maximize yields in your crop. Also make sure you carry out leaf-tissue, media and run-off analysis while you do this to ensure you get the best possible results.

Using a biodegradable iron chelate (IDHA) in hydroponics

Chelates are a very important part of hydroponic nutrient solutions as they provide a reliable source of heavy metals. Without chelates, heavy metals can easily go out of solution and become unavailable, either because they precipitate as an insoluble salt or because they are captured by active surfaces with a high affinity for metals. Among the heavy metals, Fe is the most important to chelate as it’s usually present in the largest concentration and is the most easily taken out of solution by the factors mentioned above.

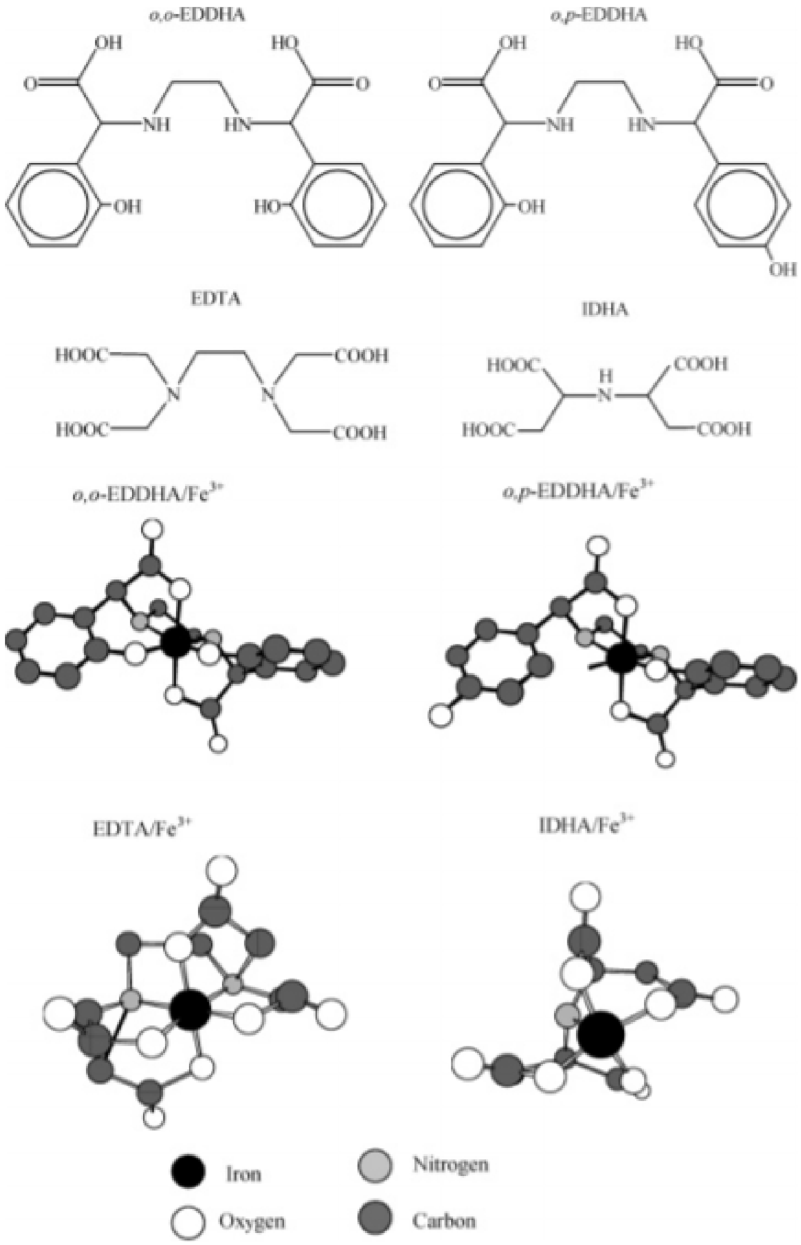


Figure 1. Chelating agents and chelates described in the text.

Models for different Fe chelating agents, taken from [this paper](#).

Commonly chelating agents such as EDTA, DTPA and EDDHA are used in solution and they do a great job in providing adequate supplies of micro nutrients to plants. These three chelators have a very high affinity for Fe and therefore ensure that Fe will remain in solution and available to plants. However, a problem all of these chelating agents share is their lack of biodegradability, they all enter plant tissue and are going to be very difficult to get rid of by the plant. They can therefore accumulate in plant tissues to some extent and can cause problems of their own.

There are however some chelating agents that are both effective at protecting the heavy metals and easily biodegradable, from these, the most largely studied is perhaps imidodisuccinic acid (IDHA) whose structure is showed and compared with the other chelates in the image above. Although this chelating agent shares some common structural features with traditional chelating agents its chemical structure makes it incredibly easy to biodegrade and therefore a nice candidate for fertilizer use.

Fig. 2. Visual aspect of green bean plants development in the experimental greenhouse of the Universidad Autónoma during 2006, after 15 d of treatment.

Fig. 3. Visual aspect of the green bean plants 39 d after the beginning of the treatments. Ethylene diamine tetraacetic acid (EDTA) treated plants suffer from fungus infection while control plants presented typical multi micronutrient deficiencies.

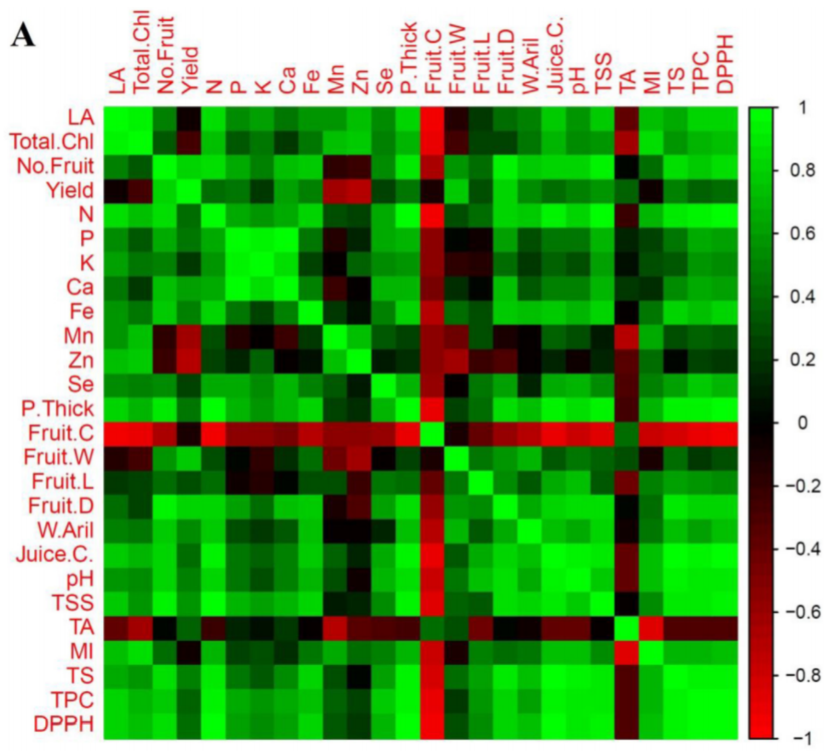
Comparison between EDTA, IDHA and a control, taken from this paper

Several papers have compared IDHA fertilization to traditional Fe chelates (here, here, here, here). Although the IDHA is usually less stable in solution – as it would be expected given its chemical nature – it tends to give better results in terms of absorption and fertilization compared with the other Fe chelates. Given that it is also completely non-toxic to the plants – while the other chelates make the plant deal with the non-biodegradable aspects – plants fertilized with IDHA can actually be healthier. The image above, showing a comparison with EDTA – shows how the IDHA plants were not affected by a fungal infection that ended up affecting the EDTA treatment.

This does not mean that IDHA is the natural best choice for an Fe chelate. Some of the above studies have shown that IDHA can easily be captured by some media and its lack of stability implies that it is not a good choice for extended use in recirculating systems. However IDHA can be a better choice if the media used allows for it and the grower is able to apply it with its biodegradable nature in mind or if the desired products needs to be free of traditional chelate contaminants. In some cases – as mentioned before – it can actually be a significant improvement over traditional chelates.

Selenium in hydroponic culture

The element selenium (Se) is not commonly used in hydroponic culture – as it's not necessary for plant life – but the fact that it's necessary for human life has meant that plant enrichment with selenium and its effects have been studied in hydroponics. Its effects however, are more than just an increase in Se concentration in plants. In today's post we'll talk about Se and what its effects in plant growth are according to some of the published literature.



Correlation map of all measured plant properties in Se application (from this study)

Different studies can use different forms of Se, so it's important to find out whether a study uses a source of Se cations, like Se chloride or a source of Se anions, like sodium selenate. If you want to reproduce the results you will need to match the exact source used, as using a different source can lead up to completely different results. Most studies focusing on Se use it in concentrations around 0.1 to 0.5ppm, although some studies do go as far as 5-10ppm, especially when studying the effects of the salts where Se is present as a cation.

Although most studies related to Se focus on the fortification of fruits, many studies also measure yield and plant quality related parameters in order to obtain as much information as possible. In this study of Se used in tomato plants there was a substantial enrichment of Se and a delayed ripening but there were no substantial effect on plant growth. However post-harvest characteristics of fruits were significantly improved by Se. Other studies on tomatoes, like this one, have however found improvements in yields when using Se.

Other studies like this one on curly endive or this one using Se nanoparticles in pomegranate, do show significant improvements in plant characteristics from using Se. In the pomegranate study, an 1.35 fold increase in the number of fruits was achieved, a very impressive mark given the characteristics of the treatment.

Plant species	Conc. of selenium as nutrient	Conc. of selenium as toxin	References
Ryegrass (*Lolium perenne*)	1 mg kg^{-1} soil	10 mg kg^{-1} soil	Hartikainen et al. (2000)
Wheat (*Triticum aestivum*)	–	0.2 mg kg^{-1} soil	Tripathi and Misra (1974)
Mung bean (*Phaseolus aureus*)	–	4 and 6 mg L^{-1}	Aggarwal et al. (2011)
White clover (*Trifolium repens*)	–	330 mg kg^{-1} Se in shoot tissue	Mikkelsen et al. (1989)
Rice (*Oryza sativa*)	–	2 mg kg^{-1} in plant tissue	Mikkelsen et al. (1989)
Mustard (*B. juncea L*)	0.5 mg kg^{-1}	–	Singh et al. (1980)
Wheat	1 mg L^{-1}	5 mg L^{-1}	Peng et al. (2001)
Soybean (*Glycine max*)	50 mg L^{-1}	–	Djanaguiraman et al. (2005)
Mung bean	0.5 and 0.75 mg L^{-1}	–	Malik et al. (2012)
Lettuce (*Lactuca sativa*)	0.1 mg kg^{-1}	–	Xue et al. (2001)
Strawberry (*Fragaria ananassa*)	1 mg kg^{-1}	–	Valkama et al. (2003)
Spirulina (*Spirulina platensis*)	≤150 mg L^{-1}	–	Chen et al. (2008)
Soybean (*Glycine max*)	Selenium as seed treatment (5 mg L^{-1}) and foliarspray (100 mg L^{-1})	–	Djanaguiraman et al. (2004)
Sweet Basil (*Ocimum basilicum*)	Foliar spray as 10 mg Se dm^{-3} solution	–	Hawrylak-Nowak (2009a)

Table taken from this review article

Selenium can also be a defense against temperature and salt stress. This article on peppers shows that an application of foliar selenium can help reduce flower drop rates and other adverse effects of temperature stress in these plants. This article on wheat seedlings, shows that selenium can also be protective against salt induced stress, preserving root growth under these adverse conditions.

It is also worth considering that Se can also become toxic to plants at anything but low concentrations. This review, which goes significantly into the articles that had been published up until 2014, goes deeply into this particular issue. The table above is particularly useful, as it shows the ranges of applications and toxicities for some plants. It is within the conclusions of the above review – as we have seen in the articles shown before as well – that Se can be used as an effective additive, stress protector and growth promoter when used in adequate amounts and forms (remember, cationic and anionic forms are different!), while it can become toxic and damaging if used without care.

Five ways to save money in hydroponics

Commercial hydroponics can be extremely expensive, given the technological complexity and supplies required for a successful crop. The biggest costs are usually related with the initial setup but subsequent crops can also become very expensive, especially if you are using boutique fertilizers or additives that can get very expensive very quickly. Today I want to talk about five ways in which you can save money in a hydroponic crop from a crop-cycle perspective.

Avoid buying liquid concentrates as fertilizers. Liquid fertilizers have some intrinsic advantages – like their homogeneity – but they contain a lot of water, which means that you will need to ship more than one pound of water for every pound of fertilizer you get. This will increase the cost of the fertilizer significantly, even if you're buying fertilizers in bulk for a commercial crop. When buying single bulk or blended fertilizers make sure you always buy solids to greatly save on these costs.

Prepare your own blend of fertilizers for macro nutrients. The most complicated part of fertilizer preparation usually deals with the micronutrient portion of fertilizers, if you want to be as simple and cost efficient as possible you can actually buy this portion – some companies specifically sell the micro part – and then prepare all the macro fertilizer blends yourself. You can then hire a consultant or read the scientific literature to get a formulation you can then use to prepare your macro portion from bulk commercially available fertilizers (which are extremely cheap).

Prepare your own foliar treatments. Foliar spraying can greatly reduce problems and increase crop yields, so it is usually a no-brainer to make sure you use foliar sprays within your crop cycle. Some of these foliar additives can be very expensive though, but it can be very cheap for you to prepare your own additives if you have the proper know-how.

Use a recirculating nutrient system. Drain-to-waste nutrient setups are extremely wasteful. If you want to have a crop that is as cheap to run as possible you will need to go to a proper recirculating setup. Once you do this you will be able to use your recirculating solutions for weeks before having to carry out a nutrient change and, even then, there are some techniques that might allow you to keep your nutrient solution for even longer. Imagine if you only needed to prepare/change nutrients once every blue moon.

Make sure you use silicon additives. Many growers fail to use silicate containing additives within their crops and generally suffer from a far greater chance of having losses due to fungi. Potassium silicate is extremely cheap and with it you can make your own silicon containing additive that you can use to greatly fortify your crop against fungal disease. A small additional expense can save you a lot of loss and heartache down the line. You can a save a lot of money by avoiding commercial hydroponic silicate products and instead making your own silicate additive yourself from potassium silicate.

When implemented, the above changes can help a commercial operation save tens to hundreds of thousands of dollars per year in nutrients, additives and crop losses. Even only implementing a couple of the above can help a mid sized operation save a ton of money in just fertilizer if, for example, in-house macro fertilizers are used, or if a recirculating system with proper nutrient management is established.

Of course, the above steps are not trivial so I would recommend anyone attempting to do them for the first time to get someone with experience in the hydroponic industry to guide their hand through the process. That could either be me or any other highly experienced consultant in the field of commercial hydroponic growing and nutrients management. If you have enough time and the inclination to do so you could also try to learn the above things yourself from scientific literature and online resources, but if you choose to do so I would advice you try to implement what you learn in smaller crops before scaling to larger projects.

Using electro-degradation to enhance yields in recirculating hydroponics

The efficient use of nutrient solutions is a very important topic in hydroponics. Although some commercial growers use run-to-waste systems where solutions are not recirculated, the economics of fertilizer use often demand re-circulation in order to enhance nutrient utilization and maximize growing efficiency. However one of the biggest problems found when circulating nutrient solution continuously is the build-up of plant exudates, which can be toxic and detrimental to plant growth.

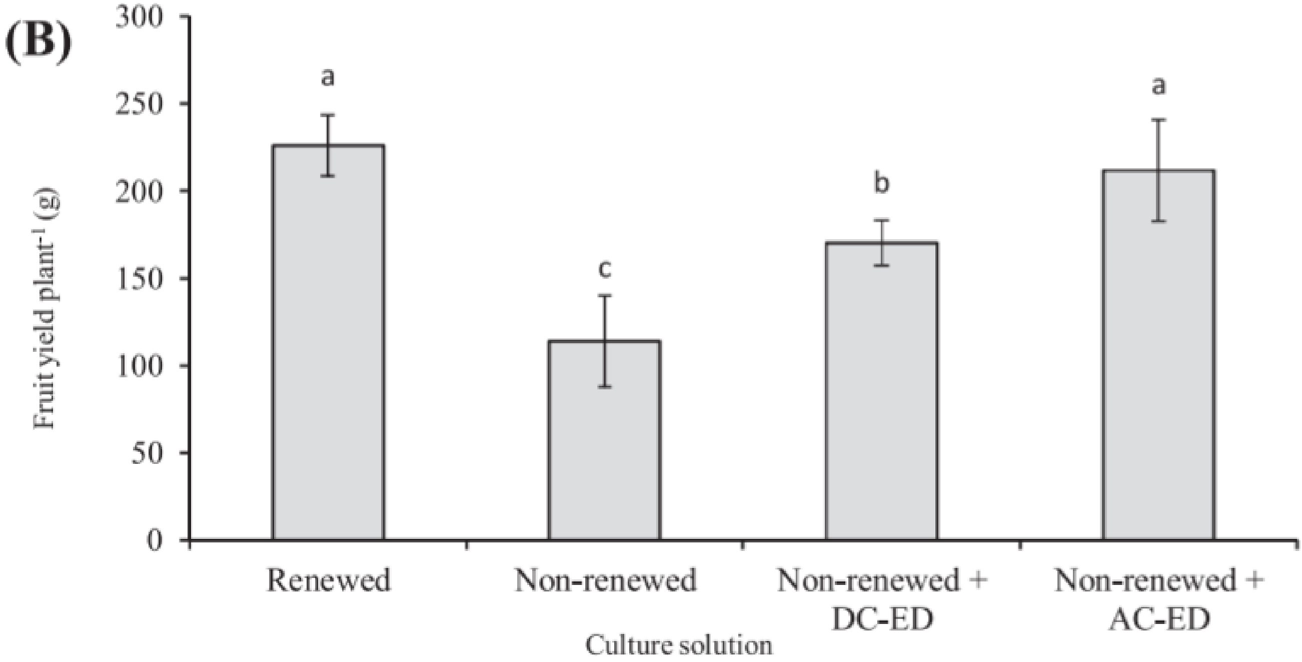


Image taken from this article

Several solution for this have been studied historically, most commonly the use of filtration systems – such as activated charcoal cartridges – to capture these exudates and prevent their accumulation. The problem with this approach is that activated carbon – or other filters – are not neutral to some of the components of nutrient solutions and might disproportionately and efficiently capture metal chelates and eventually cause nutrient deficiencies. There are some ways around this – such as changing the formulations or replenishing solutions after filtering – but both are far from ideal.

More recently a paper has been published showing how electro-degradation can actually alleviate this problem by destroying these exudates – which are commonly organic acids – in nutrient solutions. The paper talks about how they used this technique to treat recirculating solutions in strawberry, eliminating autotoxicity and increasing fruit yields substantially.

The technique is very simple, basically using either a DC or AC current passed through an electrode that the solution circulates through, destroying the problematic molecules in the process. The first image in this post clearly shows how not renewing the solution causes important problems with yields that are completely removed by the use of the AC based electro degradation.

Table 1
Changes in mineral nutrients after application of electro-degradation of nutrient solution in no plant experiment. Electro-degradations were applied in 10 l of 25% standard "Enshi" nutrient solution with 400 μM L^{-1} benzoic acid for 24 h. (Experiment II).

Electro-degradation	NO_3^- (ppm)	$P_2O_5^-$ (ppm)	K^+ (ppm)	Ca^{2+} (ppm)	Mg^{2+} (ppm)	Fe^{3+} (ppm)
Control[a]	687	37.5	7.9	49.9 a[d]	16.2	3.5 a
DC-ED[b]	658	35.8	7.6	41.6 b	13.8	2.2 b
AC-ED[c]	669	37.5	7.2	52.6 a	15.4	3.4 a
Significance	NS	NS	NS		NS	

[a] Electro-degradation was not applied.
[b] Electro-degradation was applied using "Direct Current".
[c] Electro-degradation was applied using "Alternate Current".
[d] Means within a column followed by different letters are significantly different and NS indicate non-significant according to the Tukey's test at $P < 0.05$.

Image taken from this article

Another advantage of this technique is that – contrary to filtering techniques – there is little loss in the amount of nutrients in solution when performing the AC electro-degradation. Since the oxidation/reduction of the metal chelates used is highly reversible, the actual concentration of these elements in solution remains practically the same after treatment. You can see this in the image above, where there is no statistically significant change for the concentration of nutrients in solution.

The paper concludes suggesting a treatment of 24 hours (for 300L in the experiments) every three weeks, to completely recover from the exudates present in solution. For this AC application they used a frequency of 500Hz at 14V with an electrode area of around 53 square centimeters, made of titanium metal. For this process you need an inert metal or conductive material that will not react at the potential values used. You can buy titanium metal tubes – which are not expensive – to build an anode/cathode pair to carry out this experiment. *Note that the frequency and voltage characteristics are vital so using a proper power supply to generate them is of the highest importance.*

The above technique is novel and easy to build for treating commercial hydroponic solutions. It is far easier and economic compared with filtering techniques and can be applied from smaller to larger scale growing operations.

Using machine learning control methods in hydroponics

Properly controlling the hydroponic environment is perhaps one of the most challenging tasks the modern grower must face. Either with a small grow room or a big green house, it is difficult to properly control variables such as temperature, humidity, pH and nutrient concentration, ensuring they are all kept in tight ranges with the proper controlling actions always being applied. Today we’re going to talk about some of the research done into advanced control systems and how using these could help you boost your crop yields.

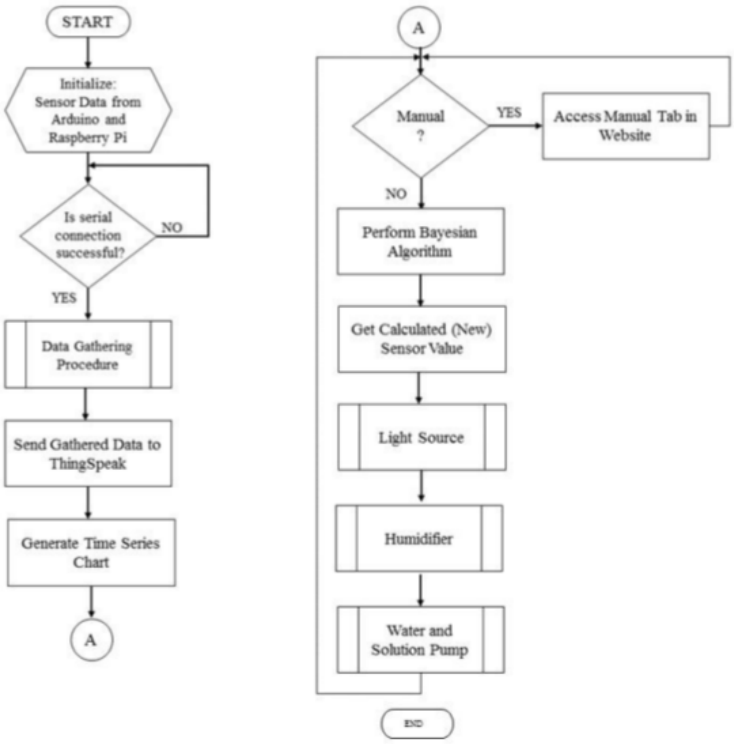
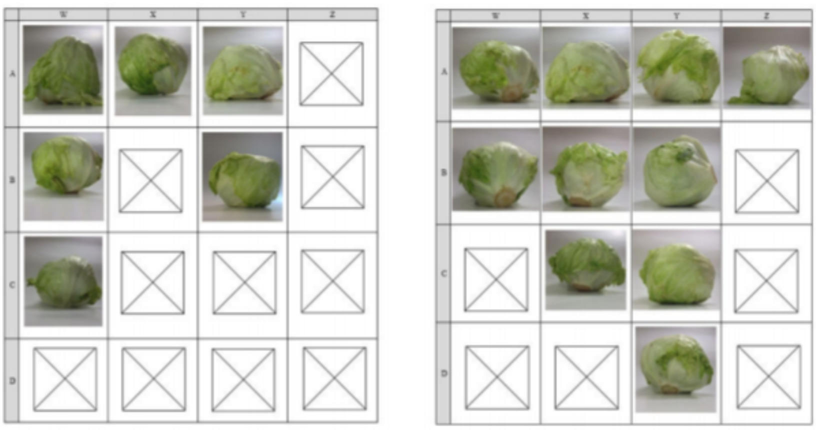


Fig. 2: System flowchart

Control flow algorithm taken from [this paper]



(a) Manual Control (b) Automatic Control

Fig. 7: Actual yielded crops matrix

Crop result comparison taken from [this paper]

Hydroponic crops are dynamic systems, with plants continuously affecting their environment and demanding control actions in order to keep conditions constant. For example plants will tend to transpire water and absorb carbon dioxide during their light cycle, so in order to keep humidity and carbon dioxide concentrations constant you might need to turn on humidifiers, dehumidifiers, carbon dioxide generators, etc. Knowing what action needs to be taken is not trivial and naive control implementations – like turning on humidifiers, AC systems, etc when some thresholds are reached – can cause problems where sensors fight each other (for example a sensor trying to increase ambient humidity and another trying to raise temperature) or even fail to trigger.

In order to provide better control, researchers have created systems that rely on machine learning – systems that can learn from examples – in order to learn what control actions are needed and execute them in order to provide ideal control to a hydroponic setup. A machine learning system will be able to anticipate things like the lag between turning an AC unit on and the temperature decreasing, so it will be able to be both more efficient and more accurate in the way it controls your environment. This use of automated control guided by machine learning is also known as “smart hydroponics”.

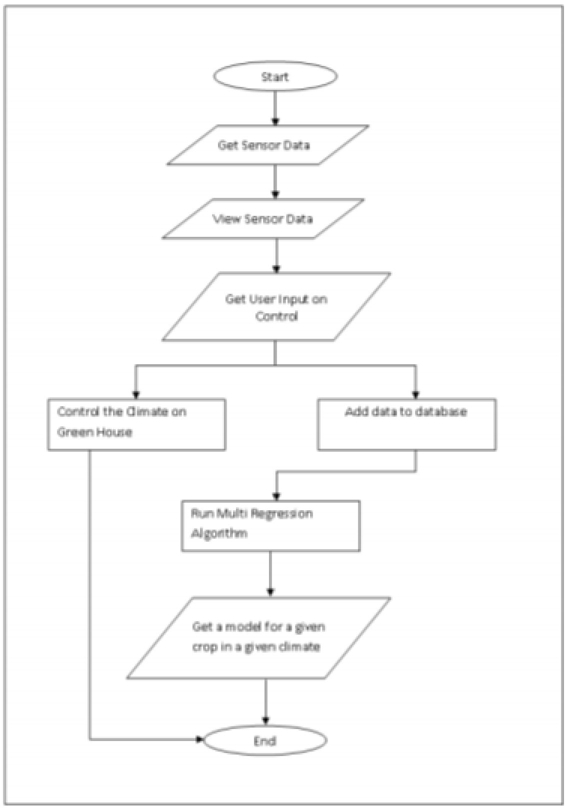


Fig. 11. Overall process of the System

Control flow diagram from this article

For example you can read this paper where growers were able to increase the yield of a crop by 66% just by ensuring they could maintain proper environmental conditions the entire time using machine learning. In this case the researchers use a probabilistic method where the system determines the probability of an action – like triggering a sensor – will cause a desired effect. As data is accumulated the system basically executes whichever action has the highest probability to lead to the desired outcome.

There are other papers on the subject. In this one a deep learning neural network is used to perform a similar control role, although the quantification of improvements in this paper is not sufficient to claim that the control method would have been an improvement over a traditionally managed hydroponic setup, as the comparison is made between a soil control, not a hydroponic control with no automated environmental management.

This paper uses a simple IoT sensor control system and a multivariate regression approach in order to control the environment in a hydroponic greenhouse, this system was created with the aim to be cheap and usable in developing countries.

Although there are now several different demonstrations of this being done in the literature there still does not seem to be a commercially mature technology to carry out this task and the implementations seem to still be tailor made to each particular situation. However the modeling techniques used are not exceedingly complex and even modest commercial growers could – nowadays – afford to setup something of this nature.

With a computer, some arduinos, raspberry pi computers, sensors and time and effort a grower could definitely setup a very nice, machine learning based control system to benefit from the above described technologies.