Monitoring the quality of fertilizer stock solutions

Hydroponic concentrated nutrient fertilizer manufacturers are not held to any routine quality standards by regulatory authorities in most countries. Although fertilizers need to be properly registered and their intended minimum compositions are shared with the public, the manufacturer never guarantees that each batch of the product will comply with any sort of quality standard and it’s therefore possible for hydroponic nutrients to come out of a factory with compositions that significantly deviate between batches. People who make their own fertilizers are also not free from problems either, as issues further down the chain – with the fertilizer raw inputs – or issues related with human error, can and will still happen.

Because of these problems, a very important part of every hydroponic grower’s process should be to establish some quality guidelines to evaluate whether a given batch of nutrients – either bought or self-made – complies with what is expected and can therefore be used in the hydroponic crop. In today’s post I will talk about the properties that you can measure in order to ensure that the quality of your inputs is sustained through time and how these measurements should be done.

These are two measurements that should always be done whenever you receive or prepare a new batch of hydroponic nutrient stock solution:

Density of the stock solution: The density of a hydroponic stock solution should always be measured and recorded. The density needs to be measured accurately, using a pycnometer and an accurate enough balance (+/- 0.01g). A 5 or 10mL pycnometer would be recommended and the balance should be able to measure up to at least 50g, to ensure that the measurement of the final weight of the pycnometer will be in range. You should first weight the empty and dry pycnometer, then fill it with liquid to the brim, place the stopper – some liquid will spill, this is how it's intended to work – then wipe any spilled liquid and weight the full pycnometer. The difference in weight divided by the pycnometer volume will give you the density. Make sure you also record the ambient temperature when the measurement is made.

pH of the stock solution: You can use a pH meter to determine the pH of a sample of the stock solution. You can use the regular pH tester you use to measure the pH of your hydroponic nutrient solutions, however make sure the pH meter does not remain for too long in the stock solution – more than what's

necessary to make the measurement – and wash it with distilled water and store it in pH meter storage solution as soon as the measurement is done. Also make sure the pH meter is calibrated right before making this measurement.

If any compounds are added incorrectly or the composition of the raw inputs was in anyway wrong, the above two parameters – pH and density – will tend to change, as they depend very strongly on the composition of inputs being the same. Of course, there are mistakes that can go undetected in these two domains but a stock solution that always records the same across batches will tend to be the same chemically. Every time you receive or prepare new solution record the above and ensure you never use any solution that deviates more than -/+ 5% from the median you have on your record. The deviation of the above two parameters also serves as a way to control how reproducible the manufacturing process of the stock solution actually is.

If there is a strong mismatch in these measurements when compared with the median of all past values, then you need to continue to actual chemical analysis of the nutrients to figure out what's wrong.

If you prepared the fertilizer yourself then it becomes important to check notes – always keep records of weights that are added when preparing solutions – and see if there were any changes in the chemical suppliers of any of the used inputs. Sometimes the quality and composition of certain chemicals can change dramatically between suppliers, so making changes from one to another can often require chemical analysis to ensure that the composition stays the same. A good example can be potassium silicate, where the exact grade and potassium to silicon ratio of the raw material can change a lot depending on the exact fabrication process used by the company making it.

Another important point is the accuracy of the instruments

used for the preparation of solutions. Sometimes the problem is that a scale or a volume measuring device lost calibration and generated errors in a previously unseen range. This can be particularly problematic if different instruments are used to measure different inputs, which can make some inputs subject to bigger errors that others and can therefore change the ratio between different nutrients in the hydroponic solution.

Why red and blue LED grow lights never took off

Anyone who has been growing plants for a while has probably seen a chart showing the absorption profile of chlorophylls A and B, as shown in the image below. From this it seems that most of the light absorbed by plants has a wavelength below 500 nm or above 650nm so it seems incredibly straightforward to hypothesize that plants can be effectively grown just using light in these regions. The commercial answer to this hypothesis came in the form of the red/blue growing LED light, which give the plant energy that it is “best suited” to absorb and avoids “wasting” any energy in the generation of light that will not be absorbed anyway (but just reflected away by the plants). However these grow lights have been an overall failure so far – with the vast majority of the industry now shifting onto full spectrum LED lights – why has this been the case?

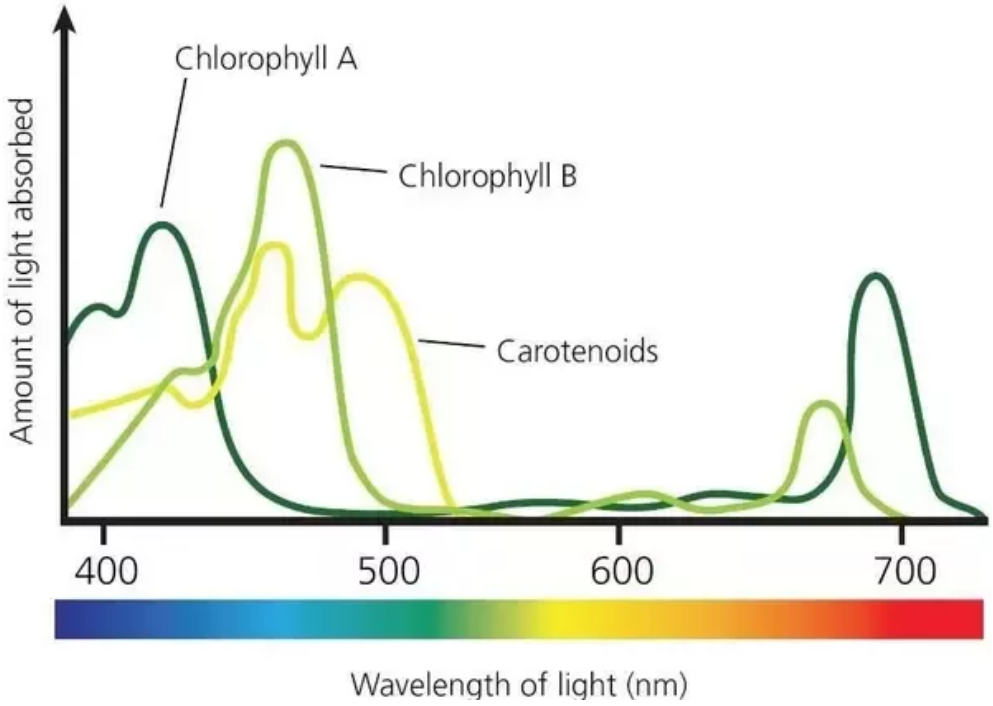


Image showing the absorption spectra of Chloropyll A, B and carotenoids

When the cost of red/blue lights dropped enough, there was a significant move to evaluate them in the scientific community to figure out how they affected plant growth. It quickly became clear that plants could be grown with these new lights and that the products could be as healthy as those produced under normal full spectrum lights. However some issues started to become noticeable when these red/blue lights started to move onto larger commercial applications. Although the commercial application of these lights in large fruiting plants is practically non-existent due to the high cost of supplemental lighting, their use was feasible for some small leafy crops – for example lettuce and spinach – which could be grown under high density conditions in urban settings. Their main use however, was in the cannabis growing space, which is one of the only high-cost crops that is grown largely under supplemental lighting when far from the equator.

Most people who tried this soon realized that the growing of plants wasn't equal to that obtained when using fuller spectrum lights, such as HPS or even metal halide lamps, even at equivalent photon flux values. Although scientific publication in cannabis are scarce, this 2016 report (1) shows

that white lights in general did a better job at growing the plants compared to the blue/red lights. Other research (2) shows that the blue/red lights can also affect the chemical composition of secondary metabolites, which makes the decision to move to red/blue LED grow lights affect the quality of the end-product.

It has also been shown that green light is not entirely unused by plants, but can actually have important functions. This review (3) goes into many of the important signaling functions of green light and why it can be important for healthy plant growth. Some researchers also started doing experiments with red/blue/green grow lights, showing the positive effects of including some green light in the composition (4). It has also been shown that other regions of the spectrum, such as the far-red (5) can also contribute substantially to photosynthesis and the regulation of plant biological processes. Ultra-violet light can also contribute substantially to the expression of certain molecules in plants. A paper evaluating cannabis under several different light regimes shows how the composition of the light spectrum can manipulate the secondary metabolite makeup of the plants (6).

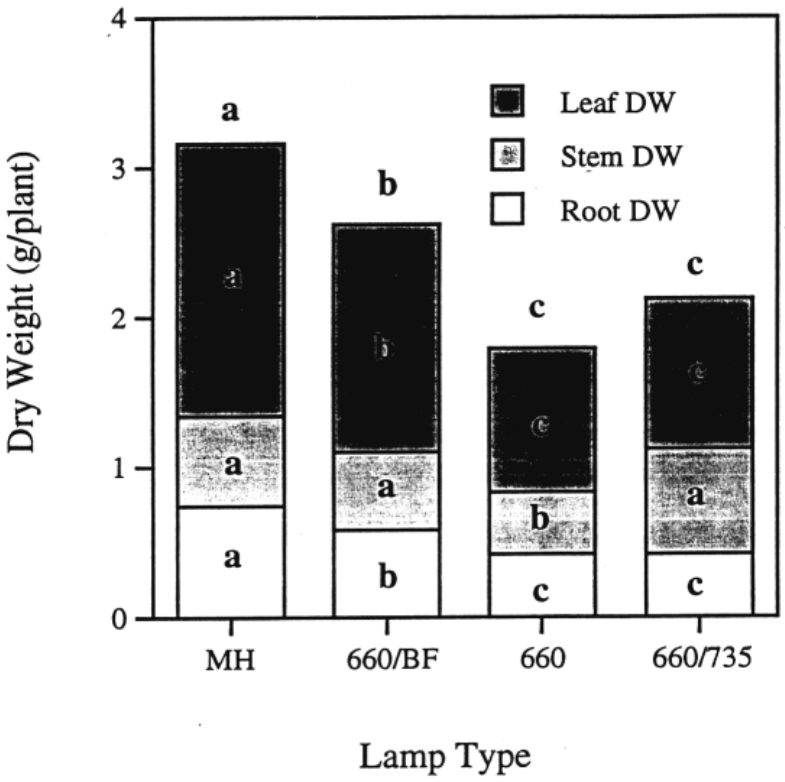


Fig. 2. Dry weight of leaves, stems, and roots of 42-day-old pepper plants grown for 21 days under metal halide (MH) lamps then transplanted under red light-emitting diodes (LEDs) plus blue fluorescent lamps (660/BF), red LEDs (660), and red plus far-red LEDs (660/735), or maintained under MH lamps for an additional 21 days. Similarly shaded portions containing different letters are significantly different based on ANOVA and protected least-squares mean separation tests ($P \leq 0.05$). The letters above the bars indicates the significance for the combined plant dry weight.

Image taken from this study (7) showing the effect of far-red light in the growth of pepper plants.

Finally, the last problem in the grow light phenomenon, especially in the case of plants like cannabis, came from the fact that plants look black under this red/blue light. This meant that growers were completely unaware of any potential problems that developed, as the plants were virtually invisible to them through their entire lifetimes. This was one of the main reasons why these lights were never widely adopted, as they made the diagnosing of nutrient issues and insect issues – which are relatively easy to diagnose under full spectrum lights for an experienced grower – almost impossible to do with these red/blue growing panels. In practice a large commercial operation relies heavily on the experience and on-going evaluation of the crop by the on-site personnel and failure to have this useful check in the process

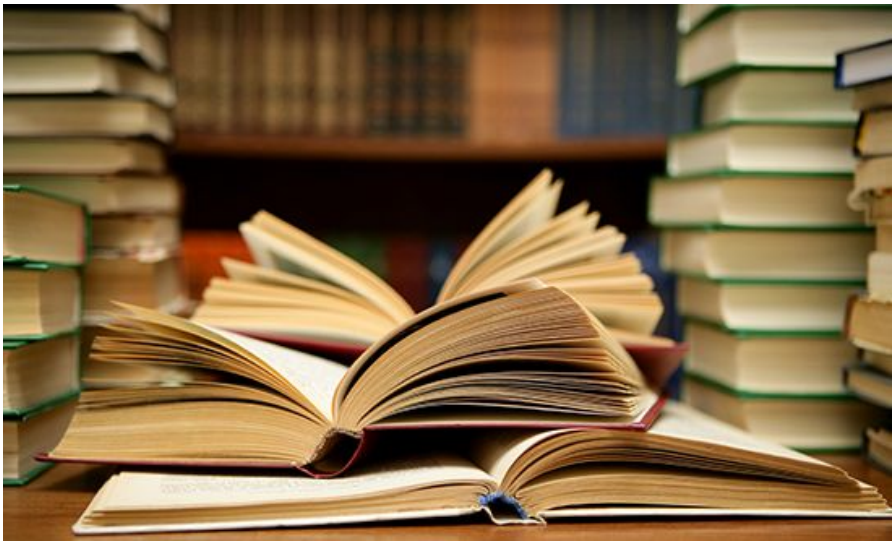
is a recipe for disaster.

The LED industry learned from these problems and has since gone into the development of full spectrum high efficiency growing panels for the hydroponic industry. These will certainly become the future and standard in the in-door hydroponic industry, especially if prices continue to come down as a consequence of mass adoption. Having full spectrum lights that are way more power efficient than HPS and MH lamps will offer growers the chance to save a lot on costs while maintaining, or even improving, the quality and yield of their crops.

In-depth books to learn about hydroponics at an advanced level

Growing plants without soil requires a lot of knowledge. As a hydroponic grower, it is now your duty to provide the plant with the needed chemical and environmental conditions that nature used to provide. Acquiring this knowledge can be difficult, as there are few well structured programs that attempt to teach in-depth hydroponics to students and many of these programs are graduate level programs that are inaccessible to the commercial or novice hydroponic grower. Although there are many hydroponic books catering to the novice – as this is the most accessible market – a lot of growers want to get to the next level by digesting books that can help them become true experts in the subject of hydroponic culture. While novice books help people get around the basics of hydroponics, true higher level books are required to

understand the causes and solutions to many problems found in this field.



In this post I am going to summarize some of my favorite books in the more advanced hydroponic domain. Going from nutrition to actual commercial and practical growing setups. I will go through some of the reasons why I believe these books are fundamental, as well as what the necessary prior knowledge to understand the books would be.

The mineral nutrition of higher plants. This classic book is used in almost all university level classes that teach mineral nutrition in plants. It covers how the different minerals are absorbed into plants, how this absorption works from a metabolic perspective and how the toxicity and deficiency of each one of these substances works from a chemical and biological perspective plus a ton of information about nutrient interactions. *This is however not a book you want to read "from start to finish"*, it is meant to be a reference book, that you can go through when you have specific doubts or want to have a better understanding about a certain element and how the plant interacts with it. It also requires a strong chemistry and biochemistry background, so it is not a book that you want to get if you don't find these domains interesting. Ideally you would go to this book to answer a question like "Why does ammonium compete with potassium

absorption but potassium rarely competes with ammonium absorption?”.

Soilless Culture: Theory and Practice. This book covers a lot of important topics in practical hydroponics. It talks about root systems, physical and chemical characteristics of growing media, irrigation, technical equipment, nutrient solutions, etc. It is one of my favorite “well rounded” hydroponic books as it covers almost all topics you could be interested in at significant technical and scientific depth, giving the user a ton of additional references for study at the end of each one of its chapters. It also focuses on giving the user a grasp of fundamental concepts that affect a given topic before going deeper into it. It will for example attempt to give you a very good explanation of why and how certain properties of media are measured before it even starts to explain the different types of media available in hydroponic culture. This book requires a good understanding of basic chemistry and physics but is way lighter in biochemistry and botany. This is a perfect book to answer questions like: “what different types of irrigation systems exist? What are their advantages and disadvantages?”.

Hydroponic Food Production: A Definitive Guidebook for the Advanced Home Gardener and the Commercial Hydroponic Grower. Howard Resh was one of the first people who produced a book for hydroponics that put together the combined experience of a lot of actual, commercial, hydroponic growers. The book is written in an easier way to read and gathers a lot of experience from the commercial growing space, with useful references placed at the end of every chapter. It can be especially useful to those who are within actual commercial production operations, as the book goes into commercial crop production in a way that none of the other books here does. This makes this book more pragmatic, specifically addressing some concerns of larger scale applications of hydroponic technology. High school level chemistry and physics should be

enough to understand what this book has to offer. A question this book might help answer is: “How do I adjust the conductivity of a hydroponic solution in a commercial setting?”.

Controlled Environment Horticulture: Improving Quality of Vegetables and Medicinal Plants: This book goes more onto the botany side and explores how a grower can manipulate a plant’s growing environment in order to guide its production of secondary metabolites. The book goes into some of the basics of horticulture but goes deeper into drought stress, thermal stress, wounding, biostimulants, biofortification, carbon dioxide and other such manipulation techniques available to modern growers. As all the ones before, this book also gives you a lot of useful literature references at the end of every chapter, allowing you to continue to explore all these topics on your own, by going to the academic literature. A question this book might help you answer is: “Which plant hormones can I use to increment the production of oil in spearmint plants?”.

The above are some of the books I will go to when I want to answer a question in hydroponics. These books will often provide me with a solid starting point for the topic I’m interested in – like some clear scientific references I can go to – or can even show me some interesting paths to explore. Usually I’ll go into the scientific literature to get an updated view of the subject, but going into the literature with a base view has proved to be invaluable almost every time.

Keeping plants short: Why is it important?

Plants have evolved to grow vertically – to reach more sunlight – and horizontally – to increase their surface area and capture more sunlight. However, vertical growth is almost always undesirable because of the many problems it can generate. With this article I am starting a series of posts about "keeping plants short" which will cover a lot of the practical methods that have been developed in order to stop and modulate the vertical growth of plants. In this first post I want to look at the reasons why keeping plants short is desirable in almost all plant species and growing conditions and give you some hints about the methods that I will be discussing in future posts about the practical actions we can take to keep our plants small, yet highly productive. So why is it important to keep plants short?

A picture of severe lodging in cereal crops (taken from this article)

Lodging prevention. Mechanical stability is very important when growing plants. Tall plants are mechanically less stable because the upper parts of the plant can apply a lot of leverage to the base of the plant. If enough weight is accumulated and force is applied – through wind for example –

the plant can easily break or the stem be displaced for the vertical position, leading to huge losses in the crop. Plants that are shorter are naturally more resistant to lodging because there is less mechanical advantage to apply leverage on the base of the plant, the plant is therefore less likely to move from its vertical position, even if some force is applied.

Ease of harvesting. The taller a crop, the more inconvenient it is to harvest the product. For fruiting crops it becomes more inconvenient to pick fruits from higher positions while for crops like potatoes more material from above the ground needs to be removed. This difficulty to harvest the fruits is the main reason why some perennial crops, like African palm, become unproductive. At some point in time the fruits are so far up that it is no longer feasible to mechanically harvest them. In hydroponic crops like tomatoes the height of the plant is limited by the mechanical constraints of the greenhouse, if a plant is shorter and more trusses per meter can be grown, then this immediately leads to an increase in potential productivity.

Table 12.1. Negative Impacts of Lodging on Wheat Yield and Quality (Typical Values after P inthus, 1973; A nderson, 1979; J ung and R ademacher, 1983; H offmann, 1992; E sson *et al* ., 1993; B erry *et al* ., 2004; B aker *et al* ., 2014 and after Results of BASF Field Trials)

Parameter	Effect
Total grain yield	Decreased by 10–40% (up to 80% in extreme cases)
1000-grain-weight	Decreased by 8–15%
Crude protein content of seeds	Relative increase by 3–20%
Carbohydrate content of seeds	Relative decrease by 10–17%
Milling quality	Decreased
Baking quality	Decreased
Presence of mycotoxins	Significantly increased risk
Costs for harvesting	Increased by up to 50%
Costs for grain drying	Increased by 20–30%

Lodging in wheat heavily affects yields and quality. Taken from this review.

Ease of transport. When a plant is shorter, the movement of nutrients and water from the roots to the leaves is easier, as the distance is smaller. Plants that are shorter need to fight gravity less and will therefore be able to transport nutrients more efficiently to their fruiting bodies. This is why the first flowers of all plants are usually the most productive – because they are the closest to the root system – and why the further away you go from the ground the smaller and smaller the fruits tend to become. Having short crops means that the top fruits and flowers will receive a higher degree of nutrition than they would if the crop was taller.

More homogeneity. Related with the above, when plants are shorter the distribution of nutrients among the plant is better because leaves, flowers and roots are all in closer proximity. Taller plants with larger inter-nodal distances will tend to have more distance between leaves and fruits, which will decrease homogeneity as the difference in light irradiation and root-to-leave transport between the nodes will

be greater. A plant with the same number of leaves and flowers with lower inter-nodal distances will have much more homogeneous products for this reason.

The above are some of the most important reasons why it is usually desirable to have plants that are short. However, we do not want plants that are just short, but we want plants that are short but preserve the same yield as taller plants. This means we must get creative and use solutions that can manipulate the plants to give us the best of both worlds. There are a potential array of solutions to this problem. For example we can attempt to directly interfere with the chemistry of stem elongation (synthetic gibberellin inhibitors), to indirectly interfere with the chemistry by trying to stimulate other processes, to do genetic selection of plants that are naturally shorter, to provide mechanical stimulation to prevent elongation, to change light characteristics to inhibit elongation or to use day/night manipulations to achieve this same goal. We will explore many of these potential solutions within subsequent posts.

Using calcium sulfate in hydroponics

Calcium is a very important element in plant nutrition and can be supplied to plants through a wide variety of different salts. However, only a handful of these resources are significantly water soluble, usually narrowing the choice of calcium to either calcium nitrate, calcium chloride or more elaborate sources, such as calcium EDTA. Today I am going to talk about a less commonly used resource in hydroponics – calcium sulfate – which can fill a very important gap in

calcium supplementation in hydroponic crops, particularly when Ca nutrition wants to be addressed as independently as possible and the addition of substances that interact heavily with plants wants to be avoided.

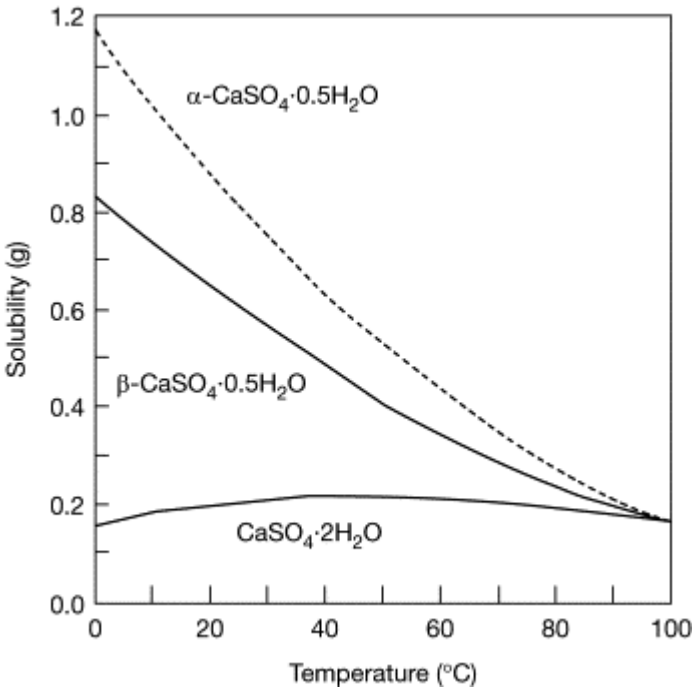
Calcium sulfate dihydrate (gypsum)

There are some important reasons why you don’t hear too much about calcium sulfate in hydroponics. Some websites actually recommend heavily against using this substance in hydroponic nutrient solutions. Why is this the case? The core issue is calcium sulfate’s solubility, with this substance traditionally considered “insoluble” in chemistry. However all substances are soluble to one or another degree – even if to an extremely small degree – but calcium sulfate is actually at the very border of what is considered a soluble substance in regular aqueous chemistry.

At 20C (68F), calcium sulfate dihydrate – the form most commonly available – has a solubility of around 2.4 g/L. In practice this means that you can have up to around 550 ppm of Ca in solution from calcium sulfate dihydrate before you observe any precipitation happening. This is way more than the normal 150-250 ppm of Ca that are used in final hydroponic nutrient solutions that are fed to plants. You could supply the entire plant requirement for calcium using calcium sulfate

without ever observing any precipitate in solution. *At the normal temperature range that hydroponic nutrient solutions are kept, the solubility of calcium sulfate is just not an issue*. To add 10 ppm of Ca from calcium sulfate you need to add around 0.043g/L (0.163g/gal). You should however avoid using calcium sulfate for the preparation of solutions for foliar sprays as it will tend to form precipitates when the foliar spray dries on leaves, the leaves will then be covered with a thin film of gypsum, which is counterproductive.

Calcium sulfate has a great advantage over other ways to supplement calcium in that the anion in the salt – sulfate – does not contribute as significantly to plant nutrition. Other sources, such as calcium chloride or calcium nitrate, will add counter ions that will heavily interact with the plant in other ways, which might sometimes be an undesirable effect if all we want to address is the concentration of calcium ions. Other sources such as Ca EDTA might even add other cations – such as sodium – which we would generally want to avoid. Calcium sulfate will also have a negligible effect in the pH of the solution, unlike other substances – like calcium carbonate – which will have a significant effect in the pH of the solution.



Solubility (g per 100mL) of calcium sulfate as a function of temperature for different crystalline forms (see more here)

A key consideration with calcium sulfate is also that its dissolution kinetics are slow. It takes a significant amount of time for a given amount of calcium sulfate to dissolve in water, even if the thermodynamics favor the dissolution of the salt at the temperature your water is at. For this reason it is very important to only use calcium sulfate sources that are extremely fine and are graded for irrigation. This is sometimes known as "solution grade" gypsum. I advice you get a small amount of the gypsum source you want to use and test how long it takes to dissolve 0.05g in one liter of water. This will give you an idea of how long you will need to wait to dissolve the calcium sulfate at the intended temperature. Constant agitation helps with this process.

An important caveat with calcium sulfate is that its relatively low solubility compared with other fertilizers means that it cannot be used to prepare concentrated nutrient solutions. This means that you will not be able to prepare a calcium sulfate stock solution or use calcium sulfate in the preparation of A and B solutions. As a matter of fact the formation of calcium sulfate is one of the main reasons why concentrated nutrient solutions usually come in two or more parts, to keep calcium and sulfate ions apart while they are in concentrated form. *Calcium sulfate should only be added to the final nutrient solution and adequate considerations about temperature and dissolution time need to be taken into account.*

Average yields per acre of hydroponic crops

I constantly talk about yield in hydroponics and how a variety of different techniques, additives and methodologies can be used to make plants more productive. However, what is the average yield you can expect in a hydroponic crop for a given plant specie? Where have these yields been measured and what can you expect your crop to yield? On this blog post I will discuss the literature around average yields in hydroponics, the problems with the expectation of average yield per acre and some of the things you need to consider when trying to consider a hypothetical growing situation. You will see that getting an expectation of how much your crop will produce is not simple and depends on a complicated mixture of variables.

Average yields per acre in hydroponic versus soil according to Howard Resh (1998, “Hydroponics food production”). I could not determine the actual source of hydroponic crop data used to get the above values or their veracity.

There are multiple literature sources of expected yields in hydroponics, many of them coming from outside the peer reviewed literature. The above table shows you one example from a book published in 1998 by Howard Resh. However if you look at the seventh edition of this book (published in 2013), you will not find the table above anywhere within it. I do not know why this table was removed from the book, but it might be related with problems with the data used to obtain the above yields, or those yields not being realistic expectations for average hydroponic setups. This does not mean in any way that the book is bad – I consider it an excellent introduction to hydroponic growing – but it does show that reducing yield expectations to simple tables can be problematic.

Below you can see another table – taken from a review article

written in 2012 – which took it from an article published in the proceedings of a conference that was held in India in 2012. These proceedings are practically impossible to find online – at least I couldn't despite my best efforts – so it is extremely hard to know where the data actually comes from. However we can see that there are large similarities between these and the numbers published by Howard Resh in the 1998 book, suggesting that these two tables actually have the same source. This table seems to have become widely used as a way to show how superior hydroponics can be when compared to soil, but the original source I can trace it to – the Howard Resh book – actually got rid of it, and people who use it in the scientific literature now quote either the reviews that quote the Indian conference proceedings or the proceedings directly. This makes me very suspicious of these values as the actual data where these values was drawn from seems impossible to get to.This can happen in scientific literature, where some widely quoted values become almost "memes", where circular references are created and the original source of the data becomes extremely hard to actually find.

Table 9. Soilless culture averages compared with ordinary soil yields

Name of crop	Hydroponic equivalent per acre	Agricultural average per acre
Wheat	5,000 lb.	600 lb.
Oats	3,000 lb.	850 lb.
Rice	12,000 lb.	750-900 lb.
Maize	8,000 lb.	1,500 lb.
Soybean	1,500 lb.	600 lb.
Potato	70 tons	8 tons lb.
Beet root	20,000 lb.	9,000 lb.
Cabbage	18,000 lb.	13,000 lb.
Peas	14,000 lb.	2,000 lb.
Tomato	180 tonnes	5-10 tonnes
Cauliflower	30,000 lb.	10-15,000 lb.
French bean	42,000 lb. of pods for eating	-
Lettuce	21,000 lb.	9,000 lb.
Cucumber	28,000 lb.	7,000 lb.

Source: Singh and Singh (2012)

Taken from this review article. The data source for these values is also not known.

So what are some actual yields in tons per acre per year for crops, as per current scientific literature that shows where the actual data came from? The answer is not very simple! Let's consider the case of tomatoes. The best information I could find on the subject was gathered in 2002 – almost 20

years ago – from greenhouse hydroponic growers in the United States at both small and large scales (1, 2). The yields for highly sophisticated large scale greenhouses that can do tomato growing during the entire year is 235-308 tons per acre per year, while for growers that can only do one crop a year – due to proper lack of climate/light control – the average yield per acre per year is around 50-60% of that. Here we can already see how technology can introduce a difference of around 2x in the results, just because of the amount that is expected to be produced. More recent data from Pakistan in 2018 (3) puts the average yield for hydroponic greenhouse tomatoes at 65.5 tons per acre, vs around 4.07 in the open field. This is a difference of around 5x with the reported yields in the US in 2002, just because of fundamental differences in growing practices and technology. I have in fact personally been at lower technology hydroponic crops that have achieved only slightly better yields than soil, with yields in the 12-15 ton per acre per year range.

For other plants accurate yield per acre per year information is even harder to find. I couldn't find scientific literature showing values – with data from actual crops – for the yields of other common hydroponic crops such as lettuce, strawberries and cucumbers. The reason might be related with the high variance in the results obtained by different growers under different circumstances. As we saw in the case of tomato producers above, things like the actual variety being grown, the climate control technology available and the actual location of the crops can play a big role in determining what the actual yields will look like.

The above implies a very substantial risk for people who want to develop hydroponic crops under unknown conditions. Creating a business plan can be very hard if you do not know how much product the business will yield. If you're in this position then I advice you do not use any of the values commonly thrown around the internet as guidance, most of the time these are

highly inflated and reflect the potential results of the most ideal hydroponic setups, rather than the average. The best guide for yields will be to look at growers that are harvesting the same crop under similar conditions in your area. If this is unavailable then the cheapest way to get this information is to actually carry out a small scale trial to see how much product you can expect.

If you are pressed to do some worst-case estimates then use the values from soil in the area where you're in as a base expectation. A hydroponic crop is always likely to do significantly better than soil, but working with soil-like production values will allow you to control your costs in a much tighter fashion if realistic expectations cannot be created either through the experience of other hydroponic growers under similar conditions or small scale experimental setups.

Three ways to judge the quality of powdered hydroponic nutrient products

Commercial hydroponic nutrients are often available as liquid concentrates. These offer a very reproducible experience for the user, with very high homogeneity and easiness of application. However, one big drawback of liquid concentrates is the fact that they contain a significantly large amount of water, meaning that shipping them is often very expensive. The solution to this is to create solid state fertilizers, where a mix of raw salts is shipped, and a concentrated stock solution or final hydroponic nutrient solution is prepared by the user.

However, solid preparations have some important issues that liquid concentrates do not have that can significantly affect the quality of the nutrition received by the plants and the reproduciblity of their results. In this blog post, we will talk about what makes a good premixed solid fertilizer and thee ways in which you can judge the quality of one.

This is a poor quality commercial hydroponic nutrient mix. As you can see there are different coarse salts that have been barely mixed (some look like rice grains, others like sugar crystals). There is no proper fine grade mixing of the salts, therefore the standard deviation of the composition of different random samples will be large.

Homogeneity of the product. Having a very finely mixed fertilizer is extremely important because hydroponic fertilizers can contain nutrients with differences in composition of even more than 3 orders of magnitude. A fertilizer might contain 10% of its mass as nitrogen but only 0.01% of its mass as iron. For that fertilizer to work effectively, any random sample draw from it must contain as close as possible to the composition on the label. However, if the fertilizer is not well mixed a random draw might deviate very strongly from the intended composition. This means that one day you might be preparing a batch of solution using a 20%N 0.001%Fe fertilizer and the next day you might be preparing one that is 10% N and 0.5% Fe.

A good quality solid fertilizer product should have a homogeneous look to it. You should be unable to determine the constituent salts from one another in the fertilizer mix. If you notice different types of solids within the product – such as pellets mixed with crystals – or any other sign that the preparation is not homogeneous then this means that the fertilizer is just a very simple mix of the raw salts, meaning that the components may separate relatively easily as a function of time through differences in their properties (such as density). Sometimes a fertilizer might be finely ground, well mixed and then pelleted – which is acceptable – but if this is the case the fertilizers should contain only pellets and all of them should have the same look to them.

If you want to really tell if the fertilizer is of good quality you can take random samples from different parts of the fertilizer – punch different holes in a sealed bag and sample from different sections of it – and send them for lab analysis. The standard deviation of the composition of the different samples will tell you how good the fertilizer is. Good solid fertilizers will have a standard deviation below 5% in analyzed samples.

Stability of the product. A good solid fertilizer product will be stable through time, since it will be formulated with salts that are as close as possible to the lowest thermodynamic state of the mixture of ions being made. Inexperienced people who venture into the fabrication of solid fertilizers will often mix salts that are used in liquid concentrates that can react when put together in solid form. These reactions often happen with a release of water that can change the weight of the fertilizer as it evaporates from the product or can cause very significant caking problems in the mixture as a function of time. In the worst cases, some substances that are hard to put back into solution might form, making the final use of the fertilizer difficult.

You can tell if a fertilizer is reacting if there are changes

in the mass of the fertilizer as a function of time or if the appearance or physical properties of the fertilizer change. Are the colors changing? Is the texture changing? All of these things can point to on-going reactions in the fertilizer mixture that can be indicative of problems with the formulation. A good formulation should change as little as possible through time.

Caking of a fertilizer product due to a reaction with atmospheric water

Easiness of dissolution. Premixed solid fertilizers for hydroponics need to be prepared to be as easy as possible to dissolve in their final application. This can be problematic depending on the inputs used, but adequate additives need to be put in to ensure that the products will not have a very hard time getting back into solution. This involves adding adequate wetting agents as well as ensuring that chemical reactions that alter solubility do not happen within the final product.

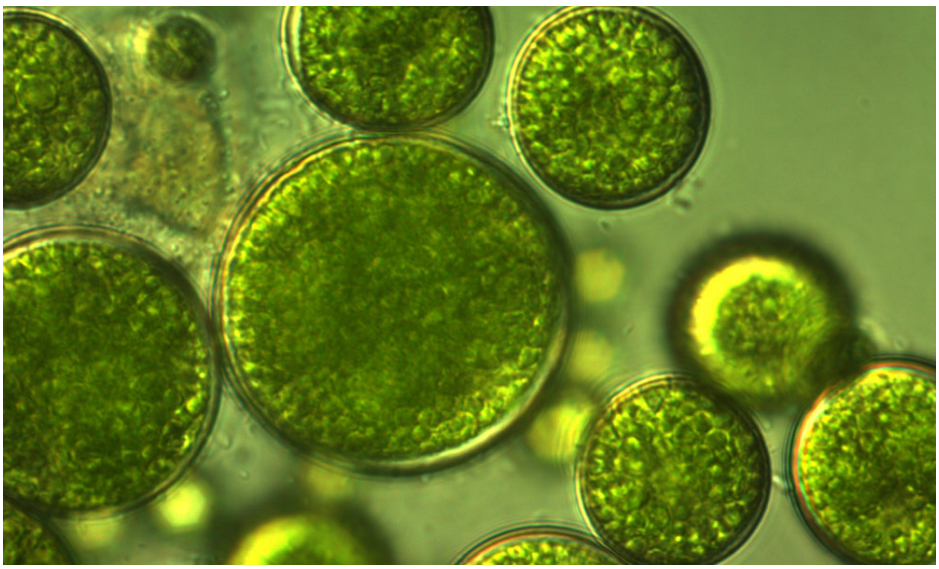
When dissolving raw fertilizers most of the product should go into solution, however – depending on the purity and source of the chemicals used – some insoluble portions might remain. A manufacturer might make the choice of using inputs that are directly mined instead of chemically purified – using for example OMRI grade magnesium sulfate – this will create a product that has more insoluble materials compared to a

product that uses more thoroughly refined magnesium sulfate. Whether this is acceptable or not will depend on the type of application required and what the priorities of the grower are, for example MRI compliance might be more important than having better solubility.

As you can see, although solid premixed fertilizers can provide significant savings in terms of shipping over liquid concentrated fertilizers, they can do so at the cost of reproducibility and quality problems.To avoid these problems I recommend you ensure the fertilizer you choose to use has been properly blended to produce low deviations in sampling, has been formulated with thermodynamic stability in mind and has been formulated considering proper solubility in the final application.

How to control algae in a hydroponic crop

Microscopic algae can be a very annoying problem in a hydroponic crop. As photosynthetic organisms they can cover all exposed surfaces that get wet with hydroponic nutrient solution and can cause a wide variety of different issues for the grower. They can also be hard to control, reason why some growers simply choose to ignore them and learn to “live with them” as a fundamental part of their hydroponic setup. In today’s article we’ll talk about some of the reasons why microscopic algae are a problem that has to be dealt with, what the different options to solve the problem are and which of these options can be the most effective.



Typical microscopic algae found in hydroponic nutrient solutions

Besides the unpleasant look of algae covered growing media, these microscopic organisms can cause some important problems in your hydroponic crop. They can deprive hydroponic solutions from some nutrients, generate substances that can hinder plant growth, serve as food for some insects (like fungus gnats) and also serve as food for other microscopic pathogens. For more information about algae and their effects you can read this paper that studied some of the effects of algae in hydroponic crops or this white paper that explains some of the main issues associated with algae in hydroponics. This paper also studies nutritional and pH effects in more depth.

The first barrier of defense against algae is to avoid them, cover surfaces that are exposed to light and nutrient solution with opaque covers and ensure that all surfaces are properly sanitized before hydroponic crops are started. Granted this is a limited solution in scope – as places like the top of media are not easy to cover – but it can provide some protection compared to a crop where no attention is paid to surfaces at all.

To deal with surfaces that have algae in them is an entirely different matter. *Algae are not easy to get rid of*. This paper goes through multiple potential treatments to get rid of algae, including the use of fungicides, insecticides and

algicides and finds that these substances are either not effective, only preventive in nature or actually phytotoxic at the concentration at which they are effective. Hydrogen peroxide is suggested as a potential solution to deal with algae, but hydrogen peroxide also causes significant stress in plant roots and its application is bound to have only limited success, with the algae coming back to recolonize – often more strongly – once the applications are finished. This paper evaluates hydrogen peroxide use even further and also shows some of the potential problems that can happen when using it to control algae and insects.

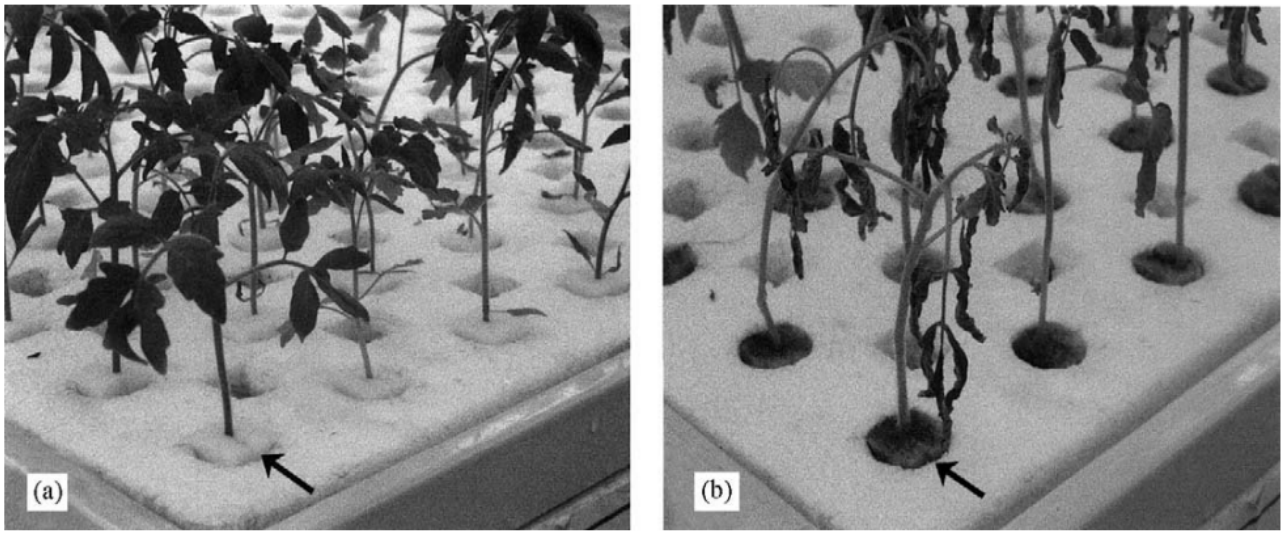


Image from this article showing plants treated with IBA (a) and plants not treated with it. You can notice the complete absence of algae in the growing media

Thankfully all hope is not lost. Around 20 years ago, experimentation started on the use of some indole derivatives – the same used to stimulate rooting in rooting gel formulations – to control algae populations. This article shows that an application of 3-(3-indolyl)butanoic acid (also known as IBA or Indole-3-butyric acid) at 10 ppm can very effectively control algae populations. The image above shows how the IBA treatment was very effective at reducing all algae growth in the media, even when nutrient solution was directly wetting the media with direct access to light. This is great news since IBA is non-phytotoxic and can therefore be used

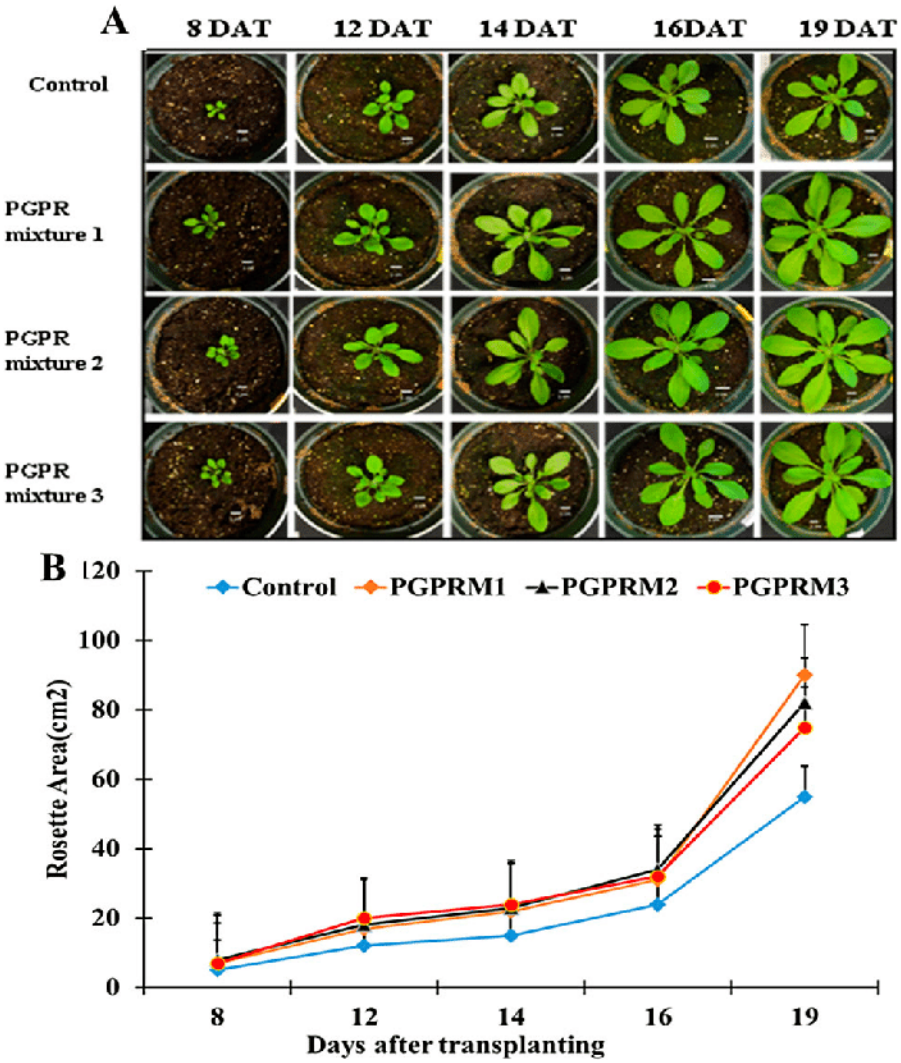
without having to cause any damage to the plants (unlike peroxide does). There is also additional evidence from independent researchers in Japan showing the effectiveness of IBA for the same purpose (see this article). Additionally there might even be some positive effects of IBA applications in crop yields, as it is shown in this paper where experiments with IBA applications were done on bell pepper. This is not terribly surprising given that the effects of IBA to stimulate root growth are very well known.

Note that although the above articles use IBA as a consistent application during the entire crop, there is little peer reviewed use of IBA applications in plants during their entire crop cycle. To avoid any potentially unknown effects – such as substantial changes in essential oil or product characteristics – it is important to test the effect in the particular plant you are growing and initially apply it only as needed to control any algae growth that might appear. Some areas might also forbid the application of substances like IBA – which is a recognized Plant Growth Regulator (PGR) – so make sure you can also use this in your crop before you even consider it for this application. This 2009 proposal to allow IBA usage in organic food production and handling goes a lot deeper into IBA, its use in plants and its potential effects.

Plant Growth Promoting Rhizobacteria (PGPR) in hydroponics

Plants did not evolve in an isolated environment but with a wide variety of different microbes. Through their evolution,

plants prospered more in the presence of certain microbes and therefore evolved traits to attract and nurture them. In turn these microbes were also selected to create even deeper mutualistic relationships with plants. Specifically, the bacteria from this group that facilitate and improve plant growth are known as Plant Growth Promoting Rhizobacteria (PGPR) and have been an extensive subject of plant research during the past 40 years. In this article I am going to talk about their use in hydroponic culture and the evidence we have about their growth promoting effects in the absence of soil.



Effect of PGPR of the genus Bacillus in soil, taken from this paper

The positive effects of PGPR in general are well established. These two (1, 2) literature reviews address the subject in depth and cite a lot of the research that has been done around PGPR for crops in general, although none of these two reviews

address their use in hydroponics specifically. What we know from all these literature is that the positive effects of PGPR are mostly attributed to three different phenomena. The first is an increase in nutrient availability for the plant, mainly through making some nutrients that are inaccessible to the plant accessible (mostly N and P), the second is through the release of phytohormones – chemical substances that stimulate plant responses – that prompt plants to develop more tissue in several different ways, and the third is that these bacterial colonies provide defenses against pathogens that could be attacking the plant if they were not present. Many different species that show these effects have been identified – some even specific to single plant species – but from those species those from the genus Bacillus, Agrobacterium and Pseudomonas have been the most widely studied and shown to be effective.

We also know from the research that the application of PGPR is not trivial and exactly how plants are inoculated with them plays an important role in the improvements they might show. Inoculation can be done in seeds, cuttings, transplants or through the entire growing/flowering periods. You can use both root and/or foliar applications, different concentrations of bacteria and different additives can also be given to try to make the inoculation steps more successful. These bacteria can also use oxygen in solutions, so using too much can also starve roots of important oxygen and cause strong negative effects before any positive effects can be seen, using too little means the bacteria die without being able to form a stable colony. The table below gives you an idea about how complex the entire application universe can be and the sort of effects that have been observed in field/greenhouse trials in soil for a wide variety of plants. *The reviews cited above contain a lot of additional references, make sure to read them if you're interested in a wider view of the available literature on the subject.*

Table 2
Effects of plant growth-promoting rhizobacteria (PGPR) application on fruit crops.

Crop	PGPR (species/strain)	Application mode	Experimental conditions	Effects	References
Apple	*Bacillus* sp. strain M3[a] and OSU-142[a], *Microbacterium* sp. strain FS01[e], *Pseudomonas* sp. strain BA-8[d] (alone or in combinations)	Root-dipping (10^9 CFU mL^{-1})	Field	Increased cumulative yield, fruit weight, shoot length, and shoot diameter in apple cv. Granny Smith and Stark Spur Golden	Karlidag et al. (2007); Aslantas et al. (2007)
	Bacillus sp.[a]	Foliar application of spores (10^7 spores g^{-1})	Field	Enhanced growth of apple leaves and improved fruit quality parameters (sweetness and moisture content)	Ryu et al. (2011)
Apricot	*Bacillus* sp. strain OSU-142[a]	Foliar application (10^9 CFU mL^{-1})	Field	Increased yield, shoot development and reduced shot-hole disease severity and incidence	Esitken et al. (2002, 2003)
Banana	*Pseudomonas fluorescens* strain CHA0[d]	Soil application of cells (2.5-3 10^{10} CFU) with or without chitin (treatment repeated three times)	Field	Increased growth, leaf nutrient contents and yield of banana plants under perennial cropping systems	Kavino et al. (2010)
Cherry	*Pseudomonas* sp. strain BA-8[d] and *Bacillus* sp. strain OSU-142[a] (alone or combinations)	Foliar application (spray; 10^9 CFU mL^{-1})	Field	Stimulated plant growth, increased yield per trunk, fruit weight and shoot length and resulted in significant yield increase	Esitken et al. (2006)
Grape	*Pseudomonas putida* strain BA-8[d] and *Bacillus simplex* strain T7[a] (alone or combinations)	Grafted plant-dipping (10^9 CFU mL^{-1}) for 60 min	Experimental glasshouse	Increased graft callusing, scion shoot growth, cane hardening, and nursery survival rate, as well as fruitfulness of the grapes in following year	Sabir (2013)
Hazelnut	N_2-fixing and P-solubilizing bacteria	Seed-dipping (10^9 CFU mL^{-1}), on one-year old seedlings	Pots, greenhouse conditions	Increased seedling and total branch length, branch number, trunk diameter, and nutrient uptake	Erturk et al. (2011)
Kiwifruit	*Bacillus* sp.[a], *Paenibacillus polymyxa*[a] and *Comamonas acidovorans*[c]	Seed-dipping (10^9 CFU mL^{-1}) for 30 min	Greenhouse conditions	Stimulation of rooting and root growth	Erturk et al. (2010)
Strawberry	*Bacillus subtilis* strain GBO3[a] and *Bacillus amyloliquefaciens* strain IN937a[a]	Seed-dipping with a formulation that contains both strains in a 2.5% chitin carrier	Field	Addition of PGPR to plug transplants resulted in healthier roots, earlier and higher total yields	Kokalis-Burelle (2003)
	Bacillus sp. FS-3[a]	Root drench (3.5×10^7 cell g^{-1}), repeated five times within 7-D intervals	Pots, greenhouse conditions	Increased fruit and leaf nutrient concentrations (N, P, K, Ca, and Fe)	Güneş et al. (2009)
	Azospirillum brasilense strain REC3[b], RLC1[b], PEC5[b]	Root-dipping (10^6 CFU mL^{-1}) for 30 min	Pots, greenhouse conditions	Increased root length, root area, and dry weight of root and shoot	Pedraza et al. (2010)
	Pseudomonas sp. strain BA-8[d] and *Bacillus* sp. strain OSU-142[a] and M3[a] (*alone or combinations*)	Root-dipping (10^9 CFU mL^{-1}) for 30 min or foliar application	Field	Increased fruit yield, plant growth, phosphorus and zinc content of leaves	Esitken et al. (2010)
	Bacillus spharicus GC subgroup B strain EY30[a], *Staphylococcus kloosii* strain EY37[a] and *Kocuria erythromyxa* strain EY43[e]	Root-dipping (10^8 CFU mL^{-1}) for 30 min	Pots, greenhouse conditions	Increased plant growth, fruit yield, chlorophyll content, relative water content of leaves, mineral uptake (N content of leaves and P content of roots), and reduced membrane injury under saline conditions (35 mM NaCl)	Karlidag et al. (2010)
	P. fluorescens strain Pf4[d], *Pseudomonas* sp. strain 5Vm1K[d]	Root drench with the two PRGB (5 10^9 CFU) and/or with arbuscular mycorrhizal fungi	Pots, greenhouse conditions	Increased anthocyanin concentration in fruits of plants grown under conditions of reduced fertilization	Lingua et al. (2013)
	Alcaligenes sp. strain 637Ca[c]	Root-dipping (10^8 CFU mL^{-1}) for 30 min	Pots, greenhouse conditions	Increased fruit yield, number and weight under high calcareous soil conditions	Ipek et al. (2014)
Walnut	*Pseudomonas chlororaphis*[d] *Arthrobacter pascens*5	Seed-dipping (10^9 CFU mL^{-1}), on one-year old seedlings	Greenhouse conditions	Increased plant height, shoot and root dry weight, phosphorus and nitrogen uptake	Yu et al. (2012)

Table showing the effects of different PGPR applications using different techniques across different plants. Taken from this review.

As you can see the effects under these conditions have been very positive, with sometimes highly significant increases in root/shoot weights and fruit/flower yields. However soil itself is not a perfect media and plants grown in soil are also not subjected to ideal nutrition. Since one of the main benefits of PGPR is to increase nutrient availability, some of these benefits might be partially or even completely negated when moving onto hydroponic culture, where we seek to provide

plants with an ideal environment. Research of PGPR in hydroponics is not very common though, as hydroponic growing has traditionally made a big deal about sterility, as growers mostly want to prevent pathogens from getting into their crops.

Ref	Plant	PGPR	Yield	Link
1	Tomato	Pseudomonas fluorescens, Pseudomonas putida	10%+	https://www.actahort.org/books/952/952_98.htm
2	Tomato	Pseudomonas fluorescens	13%+	https://www.sciencedirect.com/science/article/abs/pii/003807179390038D
3	Tomato	Pseudomonas putida, Serratia marcescens, Pseudomonas fluorescens, Bacillus spp	18-37%+	https://www.actahort.org/books/807/807_68.htm
4	Cucumber	Pseudomonas putida, Serratia marcescens, Bacillus spp., Pseudomonas fluorescens	78-121%	https://www.sciencedirect.com/science/article/abs/pii/S0304423813000198
5	Tomato	Bacillus amyloliquefaciens	8%	https://dialnet.unirioja.es/servlet/articulo?codigo=2740834

References of some trials using PGPR carried out in hydroponic conditions

Thankfully there have been some people who have led the way into the world of PGPR in hydroponic research so we have started to see some positive evidence of their use, even under hydroponic growing conditions. The above table shows you 5 references for papers that have studied PGPR in hydroponics – mainly in tomato plants – where it has been pretty well established that applications of bacteria of the genus Pseudomonas can increase yields in the order of at least 10%+. Some studies, like 3 and 4, show that significantly more gains are possible for different combinations of bacteria or application methods. I couldn't find a lot of additional studies in this direction, but the above studies start to show that the use of these bacteria in hydroponics can be positive.

A lot of questions still remain though. If these bacteria are benefiting plants because of the introduction of plant growth regulators (PGR) in solution, then we might ask if the direct

exogenous applications of these PGRs is not a better way to obtain and control the benefits without the need to maintain a live population of bacteria in a mutualistic relationship with plant roots. Research has indeed shown that the exogenous application of many PGRs can enhance the yields of different plants. Do we apply PGRs or do we keep a culture of bacteria in our media? Can we do both and obtain even better results? Sadly right now there are no answers to the above questions and a lot of additional research is needed before we even get close.

For now the research on PGPR is telling us that these bacteria work amazingly well in soil and can also provide substantial benefits for some plants in hydroponic culture under certain conditions. We know that the bacteria from the genus Pseudomonas and Bacillus are the most interesting candidates to study in hydroponics and we know some of the inoculation techniques that have worked. If you want to experiment with them in your hydroponic crops, make sure you take the above information into account. *The right choice of bacteria, concentration, inoculation method and additives can make a big difference in the results you get.*

Why do NPK labels express P and K as oxides?

If you have had any contact with the fertilizer world you have probably noticed that fertilizer labels contain N-P-K values on their front and back labels, denoting the chemical composition of nitrogen, phosphorus and potassium available within the product. However you will soon learn that while N is elemental composition – the actual percent of the

fertilizer by weight that is nitrogen – P and K are expressed in more confusing terms, mainly the oxides K_2O and P_2O_5. Why do we keep expressing these elements as oxides? Is there any actual reason why expressing them as oxides would be better? What's the point? In today's post we'll talk about fertilizer and fertilizer analysis, we'll talk about why P, K and other elements are expressed as oxides and why this continues to be the case.

Nitrogen, phoshprous and potassium are the elements represented in the N-P-K, although P and K are expressed as oxides and not pure elemental forms

I have heard people talk about the expression of K as K_2O and P as P_2O_5 as a consequence of K and P not being actually present in their elemental forms in the fertilizers but as other substances. The argument being that it is preferred to express these elements as their available forms, instead of their elemental forms. However this argument has many problems. The first is that K_2O and P_2O5 are also not present within the fertilizer, as these two are also very reactive forms of these elements. Potassium in particular is always present as K^+ ions, reason why it would make more sense to express it as elemental potassium and P is actually present most commonly as either

$H_2PO_4^{-2}$ or HPO_4^{-}, all of these pretty far away from the phosphorus pentoxide form that the label describes it as (P_2O_5 is *not* phosphate). Nitrogen is also not present as elemental N, but it is present most frequently as either NO_3^{-} or NH_4^{+} ions (although urea and amminoacids are also common forms of N in non-hydroponic fertilizers).

Why is N expressed as elemental N and K and P are not? The reason has to do with the way that these elements were quantified in the past when doing chemical analysis. Before we had access to modern techniques – such as inductively coupled plasma mass spectrometry – the elements were quantified using more complicated analysis procedures. The nitrogen was usually quantified using methods such as Kjeldahl nitrogen analysis because it would become volatile when the sample was burned, while the other elements were quantified from a calcined sample, meaning the sample was exposed to high temperatures to eliminate all water and carbon within it before the analysis. This ash would contain all non-volatile elements and when determining K and P from these ashes you could sometimes actually quantify K_2O and P_2O_5. From an analytical chemistry perspective, it made sense to express all non-volatile elements as oxides, because the concentration of these oxides was what you were actually measuring in the lab after you calcined the sample. This practice was very common in inorganic chemistry in general, because analysis of many non-volatile elements tended to follow a similar path. The above is certainly an over-simplification, you can read more about analytical methods used in the early days of fertilizers here, if you do so pay special attention to the references in that paper.

In the past knowing the composition of fertilizers expressed in this way made sense, as labs could basically eliminate an additional conversion step when reporting and comparing results. Note that in those days – 1930-1950 – there were no

pocket calculators and everything needed to be calculated entirely by hand, so saving calculation steps was considered less trivial than it is right now as someone would actually need to make all those conversions using pen and paper. If you have to analyse 30 fertilizer samples in your lab then you would rather report a number closer to the one you directly measured instead of having to do 30 additional calculations by hand to get to another number. Since all labs were measuring these elements in similar ways, everyone agreed that it made sense for fertilizer labels to be N-K_2O-P_2O_5.

We no longer do things this way, as the methods and tools available to the analytical chemist have changed through time, but we keep this trend of reporting things in this manner in order to have coherence with past NPK labels. We have measured NPK in this manner for almost a century – the era of modern fertilizers starts in the early 1930s – so it would be a nightmare to change since it would become difficult to know when looking back which values were expressed as K_2O and P_2O_5 and which ones as actual elemental P and K if the change was made.

So expressing K and P as K_2O and P_2O_5 makes little sense in the modern world. We do it because we inherited this from the birth of the fertilizer era and we do it because making the conversion in these times is trivial and maintains coherence with all our previous reports of fertilizer compositions. However it is important to realize that K_2O and P_2O_5 are not the actual forms that these elements have in fertilizers and that we simply express them this way through mathematical operations. Just image you're saying: "If the K present in this fertilizer was actually all K_2O, then it would be x% of the mass of the fertilizer".