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?

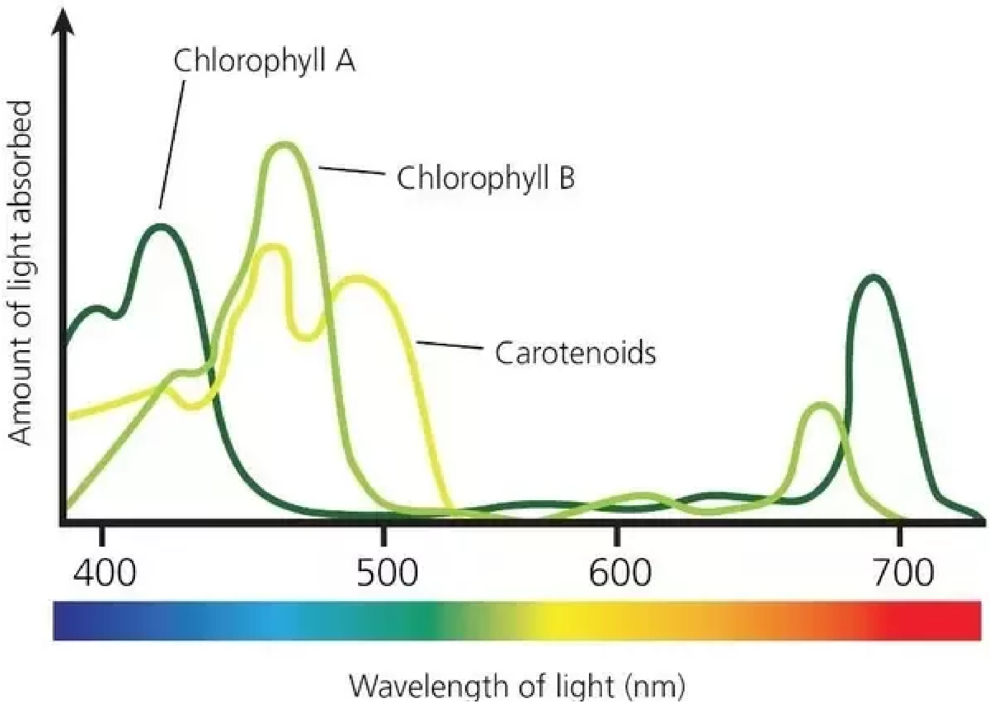


Image showing the absorption spectra of Chloropyll A, B and carotenoids

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).

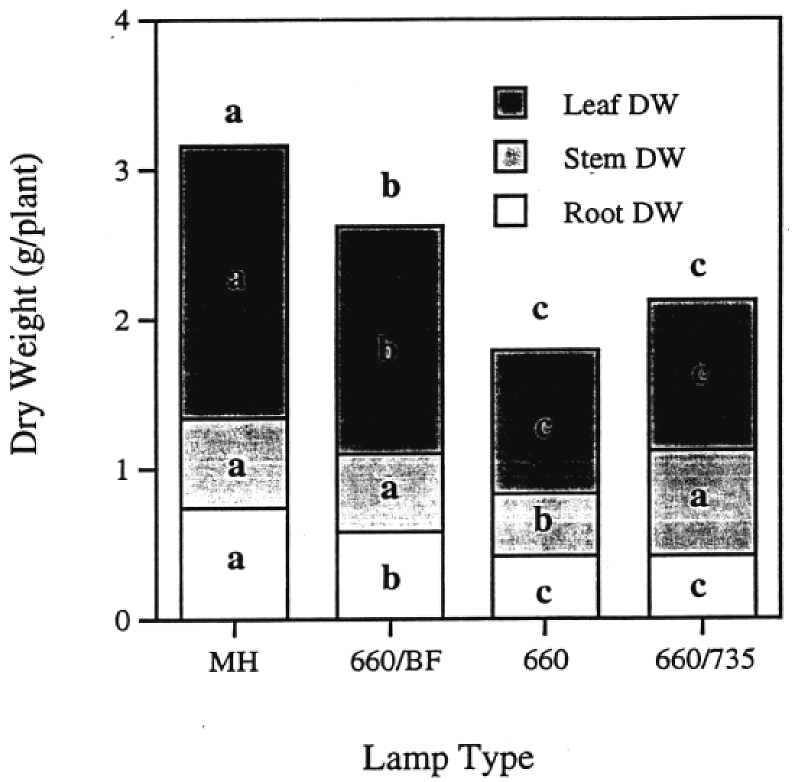


Fig. 2. Dry weight of leaves, stems, and roots of 42-day-old pepper plants grown for 21 days under metal halide (MH) lamps then transplanted under red light-emiting diodes (LEDs) plus blue fluorescent lamps (660/BF), red LEDs (660), and red plus far-red LEDs (660/735), or maintained under MH lamps for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

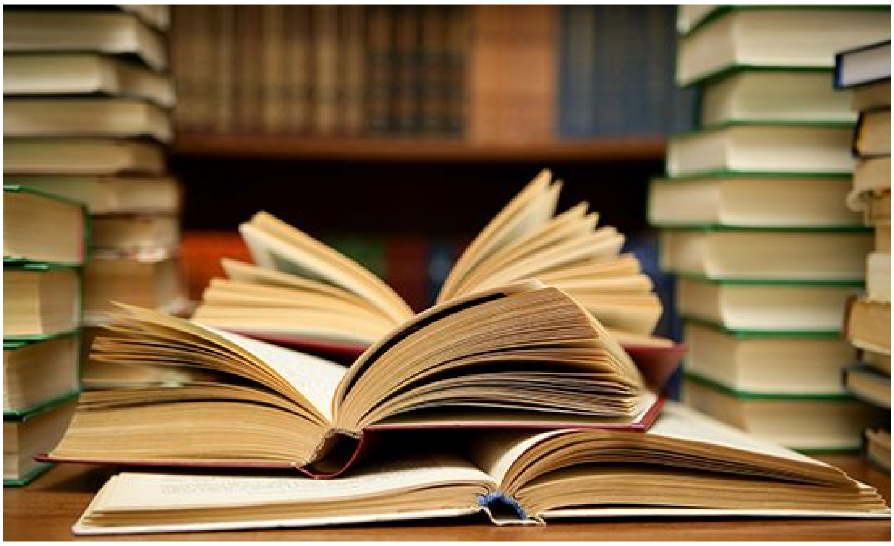
Image taken from this study (7) showing the effect of far-red light in the growth of pepper plants.

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?”.

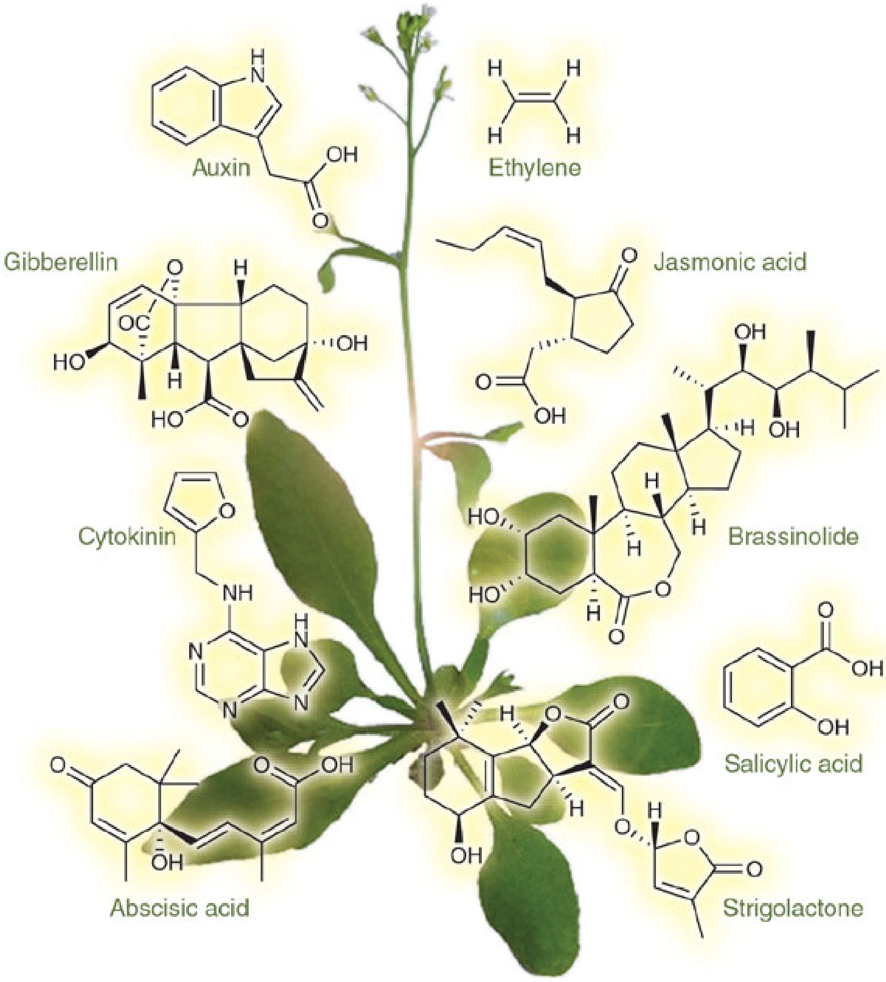
Controlled Environment Horticulture: Improving Quality of Vegetables and Medicinal Plants: This book goes more onto the botany side and explores how a grower can manipulate a plant’s growing environment in order to guide its production of secondary metabolites. The book goes into some of the basics of 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.

Six things you need to know before using plant hormones

Plant hormones are small molecules with no nutritional value that are used as chemical signaler within plants. A hormone will trigger a chemical signaling cascade that will cause the plant to carry out certain specific behavior. This fact has made them one of the most useful tools to manipulate plant growth and improve the yields and quality of many crops, especially flowering plants. This has also made them a key target for hype, with many products promising significant gains without much talk about interactions with other hormones or other fundamental aspects. In this post I want to talk about six things you should know about plant hormones, both to use them more effectively and to adequately manage your expectations when you use them. Note that although plant hormones are considered plant growth regulators (PGRs), this broad class includes other molecules – such as gibberellin synthesis inhibitors – that are not being considered in this post.

Know specifically what you want. A hormone will affect a plant in a very specific way, to achieve a specific purpose. Hormones can help you manipulate plant growth but which one you use depends fundamentally on what you want to achieve. Do you want the plant to be bigger or shorter? Do you want to have more water content in your product? More solid content? More terpenes? Do you want to fight drought conditions? Excess salinity? Insects? The specifics of what you want will guide you into choosing an appropriate hormone for your specific needs.



Examples of widely used plant hormones

Plan your hormone applications strategically. Different hormones can stimulate different processes that are needed at different points of a plant’s life. If you plan the use of hormones carefully you can stimulate root growth when plants are transplanted, then stimulate flowering or other behavior when you want the plant to express that behavior more strongly. Plants take some time to steer, they react to their environment, hormone applications at the right times can give a plant a strong signal that it should follow certain behavior and you – as a grower – can ensure that the environmental conditions are perfect for the processes the plant will be carrying out next. Hormones are the flares telling the plant where to go, you should ensure you make that a smooth ride.

There is no free lunch. Plant hormones act to cause a certain behavior to happen, but this behavior comes at a specific cost. A plant that is stimulated to produce more flowers will often grow smaller fruits, a plant that is stimulated to produce more terpenes might produce lower yields because of the additional energy spent in these molecules, a plant that grows more roots, grows less shoots while it's doing that, etc. A plant does not magically get access to more energy because it has been stimulated with a hormone, it simply chooses to act differently with the energy it is receiving.

Hormones interact with each other. A given hormone can behave in a way when it's applied and in a very different way when it's applied with another hormone. As different hormones signal different paths, the net effect is often related with how these different paths are activated. Some are synergistic, the total is more than the sum of the parts, while others are antagonistic, meaning you get less than the sum of the parts. Growers interested in hormones will often make the mistake of applying a lot of things at the same time, but they have no idea what the net effects are going to be like. When dealing with hormones introduce them one at a time and make sure you're getting a measurable positive effect before you venture into using another one with it. Incremental gains is the name of the game not "apply every hormone under the sun that has a peer reviewed paper published where it increases yields in a plant".

Concentration is everything. To make things even more complicated, a hormone might activate one signaling path when it's present at a given concentration but a different one when it's present at a much larger concentration. Using the wrong concentration for the hormone might end up causing a completely different effect or an effect so pronounced that it's negative side effects are going to out-do the positive effects. Furthermore, this can also be genetic dependent, so when using hormones on new varieties or species it is always advisable to do a concentration trial across 2-3 orders of magnitude to see where the “sweet spot” for the desired effect is. Sometimes hormones are most effective at surprisingly low concentrations – even 0.1 to 1 ppm – while other times they need to be applied in very significant amounts (100-300 ppm).

The application route and vehicle is very important. A hormone might be very effective when applied in a foliar spray, while completely ineffective when applied in a root drench. Sometimes the hormone requires specific additives or solvents to be used in order to ensure its absorption and others it needs to be applied at a very specific pH range or even just by itself. Knowing the particular application conditions of the hormone you want to use is also important to achieve the expected results.

These are some simple guidelines to consider when using plant hormones in your crop. Hormones are no miracle but they can certainly provide amazing improvements in yields and quality if used appropriately. Formulating a good hormonal regime, with adequately formulated foliar/root drenches, applied at the right times, with the right hormones, can provide amazing results. This however requires a lot of testing, a lot of effort and a lot of understanding about the plant being grown and its crop cycle. Every crop has its own genetic and environmental conditions and requires significant experimentation to achieve the best possible results.

Keeping plants short: Synthetic gibberellin

inhibitors

Plants grow both vertically and horizontally. A plant will develop branches along its stem – expanding horizontally – and the stem will grow towards the sun, making the plant taller. This vertical growth is almost always an undesirable quality, both in extensive and intensive crops, which creates an opportunity to improve plant cultures by attempting to reduce the height of plants. You can read more about why making short plants is important in this post. Although there are many potential ways to achieve this – which I will discuss in detail in future posts – this post will deal with the most powerful tools that have been developed for this purpose, a class of plant growth regulators (PGRs) known as gibberellin inhibitors or more commonly as “growth retardants”.

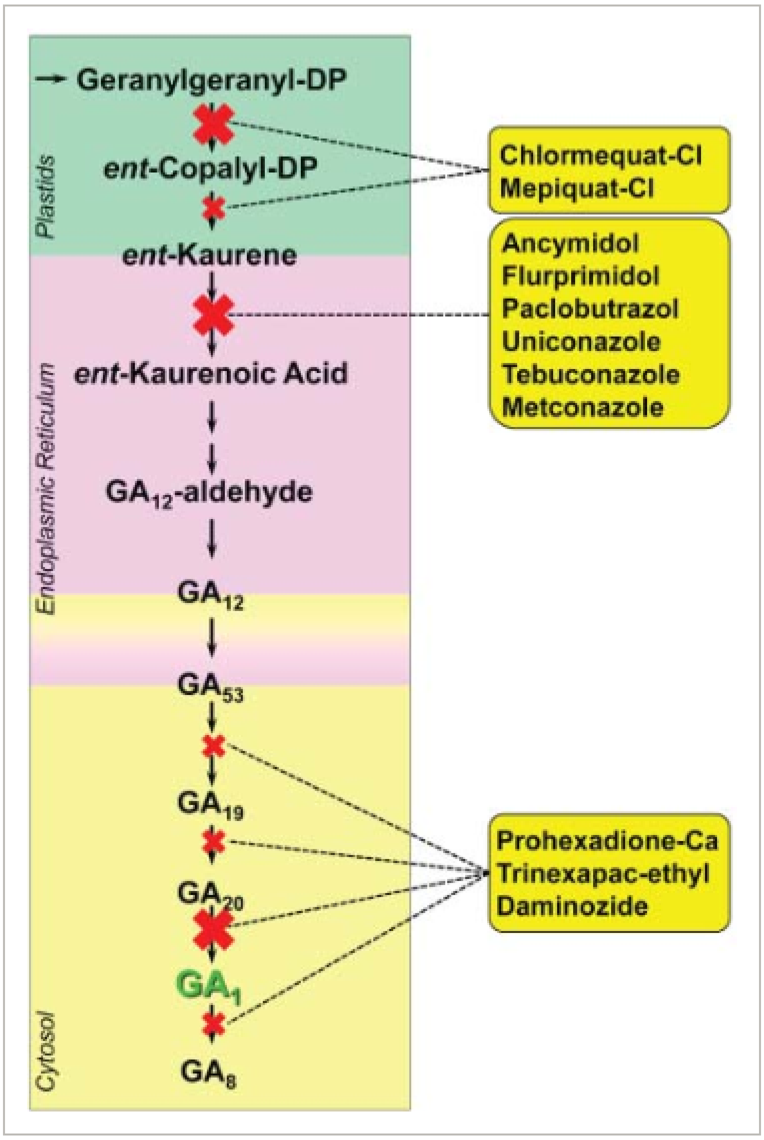


Figure 12.2 Open in figure viewer | PowerPoint

Main steps of gibberellin biosynthesis leading to biologically active GA_1 and points of inhibition by plant growth retardants. The cellular locations of the reactions is indicated by different greyscales. (The conversion of GA_{12} into GA_{53} can be located in both the endoplasmic reticulum or the cytosol.)

This figure was taken from [this article](#).

Making a plant grow shorter is no trivial task. This is because we do not want to make the plant less productive, but we want the same productivity of a tall plant in a much bushier and compact package. We therefore need to inhibit vegetative growth without affecting the flowering stages of our plant. Scientists figured out around 30 years ago that a set of plant hormones called gibberellins played a critical role in the vegetative growth of plants – especially the elongation of a plant -so these became a prime target to stop growth. If you can disrupt the gibberellin creation pathway right when the plant is supposed to stretch, then the plant will stop growing vertically without the flowering development of the plant being affected at all.

We have found several different types of compounds that can do this. The figure above shows you the gibberellin synthesis path and the steps where different molecules have been shown to disrupt it. Among the most powerful and commonly used were the ones that disrupted the conversion of kaurene to kaurenoic acid, with the most famous one being paclobutrazol. In the other groups the most commonly used ones were chlormequat and daminozide. These molecules are all part of the first generation of gibberellin inhibitors and they did exactly what they were supposed to, proving to be extremely powerful growth retardants that were able to keep plants compact and strongly increased yields in several different crops.

However it soon became evident that their toxicity and retention in plant tissue is significant. Paclobutrazol has been shown to be toxic, having developmental and reproductive effects in rats (1) although it has been shown not to be carcinogenic in humans but still very toxic to aquatic life (2). The use of paclobutrazol on food crops is therefore not recommended, but whether or not it’s actually allowed or not depends on the legislation of the country where you’re in. Some countries will allow paclobutrazol to be used as long as enough time is given between application and the development of the edible parts of the crop and then again this usually only applies to a limited number of crops where the time between use and harvest can be guaranteed to be long enough. Chlormequat and daminozide follow similar stories, although in the case of daminozide it was discovered that it was carcinogenic and its use in edible crops was completely banned world wide in the late 1980s.

Table 2. Pesticide analytes and their action levels

Analyte	Chemical Abstract Services (CAS) Registry number	Action level ppm	Analyte	Chemical Abstract Services (CAS) Registry number	Action level ppm
Abamectin	71751-41-2	0.5	Imazalil	35554-44-0	0.2
Acephate	30560-19-1	0.4	Imidacloprid	138261-41-3	0.4
Acequinocyl	57960-19-7	2	Kresoxim-methyl	143390-89-0	0.4
Acetamiprid	135410-20-7	0.2	Malathion	121-75-5	0.2
Aldicarb	116-06-3	0.4	Metalaxyl	57837-19-1	0.2
Azoxystrobin	131860-33-8	0.2	Methiocarb	2032-65-7	0.2
Bifenazate	149877-41-8	0.2	Methomyl	16752-77-5	0.4
Bifenthrin	82657-04-3	0.2	Methyl parathion	298-00-0	0.2
Boscalid	188425-85-6	0.4	MGK-264	113-48-4	0.2
Carbaryl	63-25-2	0.2	Myclobutanil	88671-89-0	0.2
Carbofuran	1563-66-2	0.2	Naled	300-76-5	0.5
Chlorantraniliprole	500008-45-7	0.2	Oxamyl	23135-22-0	1
Chlorfenapyr	122453-73-0	1	Paclobutrazol	76738-62-0	0.4
Chlorpyrifos	2921-88-2	0.2	Permethrins*	52645-53-1	0.2
Clofentezine	74115-24-5	0.2	Phosmet	732-11-6	0.2
Cyfluthrin	68359-37-5	1	Piperonyl_butoxide	51-03-6	2
Cypermethrin	52315-07-8	1	Prallethrin	23031-36-9	0.2
Daminozide	1596-84-5	1	Propiconazole	60207-90-1	0.4
DDVP (Dichlorvos)	62-73-7	0.1	Propoxur	114-26-1	0.2
Diazinon	333-41-5	0.2	Pyrethrins†	8003-34-7	1
Dimethoate	60-51-5	0.2	Pyridaben	96489-71-3	0.2
Ethoprophos	13194-48-4	0.2	Spinosad	168316-95-8	0.2
Etofenprox	80844-07-1	0.4	Spiromesifen	283594-90-1	0.2
Etoxazole	153233-91-1	0.2	Spirotetramat	203313-25-1	0.2
Fenoxycarb	72490-01-8	0.2	Spiroxamine	118134-30-8	0.4
Fenpyroximate	134098-61-6	0.4	Tebuconazole	80443-41-0	0.4
Fipronil	120068-37-3	0.4	Thiacloprid	111988-49-9	0.2
Flonicamid	158062-67-0	1	Thiamethoxam	153719-23-4	0.2
Fludioxonil	131341-86-1	0.4	Trifloxystrobin	141517-21-7	0.2
Hexythiazox	78587-05-0	1			

Table taken from here, these are substances banned for use in cannabis by the state of Oregon. You can see how several of the above mentioned growth retardants are present.

The above developments caused chemical companies to search for and develop new gibberellin synthesis inhibitors with lower toxicities and lower accumulation in plants that could be approved for use in edible crops. This led to the development of Prohexadione-Ca and Trinexapac-ethyl, which are two of the most commonly used growth retardants right now. These two have considerably lower toxicities and lower half-lives in the environment. For this reason trinexapac-ethyl has been approved for general use in places like New York (3). In this document the toxicity for mammals and aquatic life is discussed and trinexapac-ethyl is not found to be a threat to humans or animals at the maximum suggested application rate.

This is mainly due to the fact that it’s quickly bio degraded in the environment. A risk assessment made by the EFSA also reached similar conclusions (4). Another EFSA risk assessment for prohexadione-Ca also points in the same direction (5). Prohexadione-Ca is currently approved by the EPA for use in apples, grass grown for seed, peanuts, pears, strawberries, sweet cherry, turf, watercress, alfalfa and corn (6).

Optimal results with these new growth retardants also require careful consideration of the application formulation, the application time and adequate pairing of the PGR with the plant being grown . For example in apple trees much larger doses of Trinexapac-ethyl are required compared to Prohexadione-Ca to achieve the same results and trees that have been treated with Trinexapac-ethyl can have important reductions of flowers in subsequent crops (7).

With the development of less toxic and still highly active growth retardants, it might seem like a no-brainer to use these in crops to prevent elongation and increase yields. However the introduction of inhibitors in the gibberellin pathway is not without further consequence as this path is also important to guide the production of important phytonutrients and essential oils. When using these growth retardants it’s important to evaluate their effect in the quality of the product, as they can also lead to a change in the properties of the end product. For example in apples these PGRs can induce the production of luteoforol, a flavonoid they normally do not produce (8).

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 asson *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

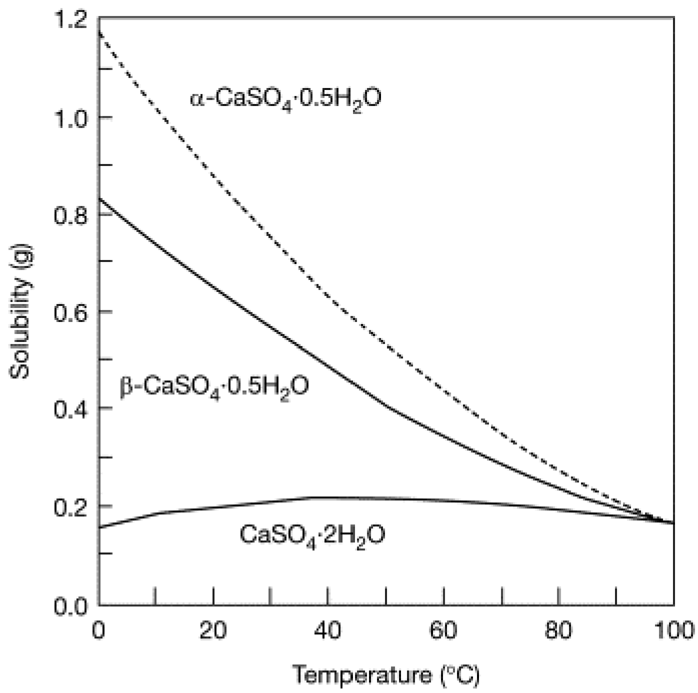
Calcium is a very important element in plant nutrition and can be supplied to plants through a wide variety of different salts. However, only a handful of these resources are significantly water soluble, usually narrowing the choice of calcium to either calcium nitrate, calcium chloride or more elaborate 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

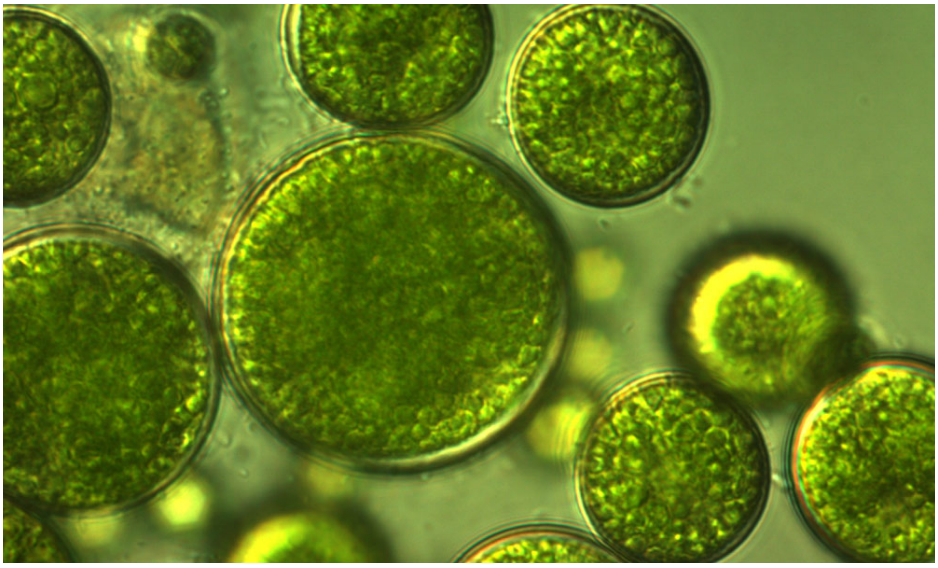
Easiness of dissolution. Premixed solid fertilizers for hydroponics need to be prepared to be as easy as possible to dissolve in their final application. This can be problematic depending on the inputs used, but adequate additives need to be put in to ensure that the products will not have a very hard 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.

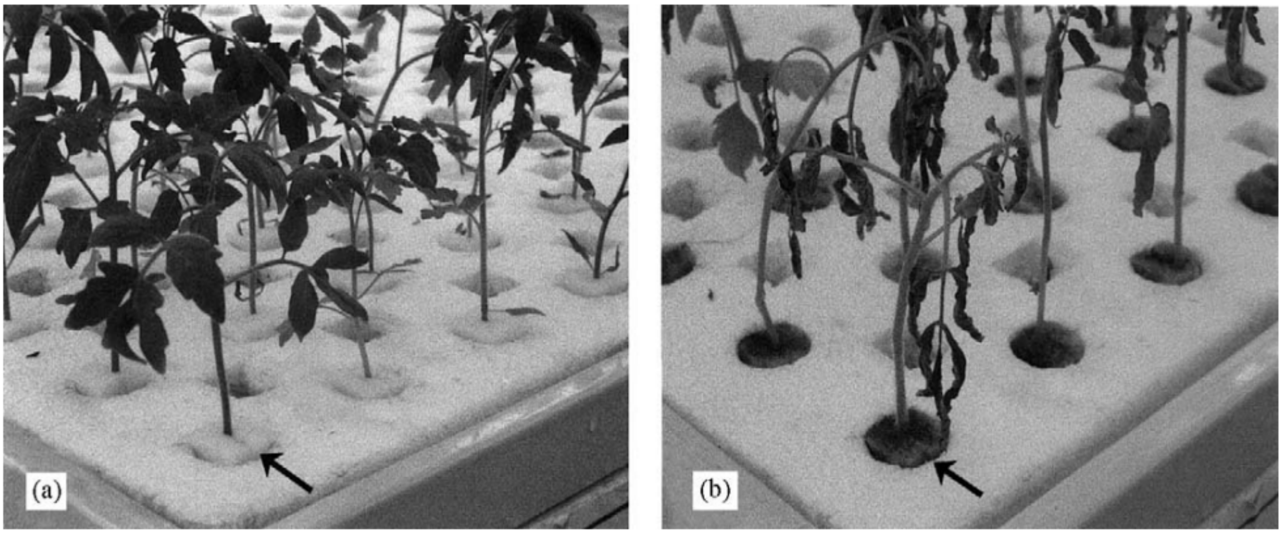


Image from this article showing plants treated with IBA (a) and plants not treated with it. You can notice the complete absence of algae in the growing media

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.

Can you use regular soil fertilizers in hydroponics?

If you have just started your journey into hydroponics you're probably wondering why you need to spend your money in hydroponic specific nutrients when there are so many cheaply available soil fertilizers sold out there. Certainly there are all plant food and there must be some way you can use all these cheap soil fertilizers to create a suitable replacement to feed your hydroponic crop. In this post I want to explain some of the key differences between hydroponic and soil fertilizers, when soil fertilizers can be used in hydroponics, how they can be used and when it is definitely a bad idea to try to use them.

Some slow release soil fertilizer being added to plants

To understand the difference between soil and hydroponic fertilizers we must first understand the difference between both growing setups. In hydroponics we try to grow plants in sterile and chemically neutral supporting media where all the nutrients are expected to be provided by the nutrient solution while in soil the media is not intended to be inert – it contains organic matter, minerals that can dissolve and living microbes – and we expect some of these to provide nutrition to our plants. Fertilizers for soil are intended to aid this process – provide material for microbes to process and supplement some of the lacking elements in the soil – while hydroponic fertilizers intend to provide all required nutrition in the forms that are mostly favorable for plants. Fertilizers for soil are often also meant to be applied once or very occasionally, while fertilizers for hydroponics are expected to be fed to the plant very frequently.

In chemistry terms, this means that fertilizers for soil will tend to contain forms of nitrogen that can be processed slowly by microbes in soil – urea and ammonium salts – while hydroponic fertilizers contain mostly nitrate salts. It is rare for soil fertilizers sold to home growers to contain large amounts of nitrates because these are easily washed aware by rain, are strong pollutants of underwater ground sources and are only shortly available for plants due to their high mobility in soil. However ammonium and urea are a terrible idea in hydroponics since ammonium fed frequently strongly acidifies the media and plants supplied their nitrogen only from ammonium in solution will tend to show toxicity issues quickly. Soil fertilizers rely on bacteria to convert this ammonium and urea to nitrate in a slow process, hydroponic fertilizers do not, they contain nitrate which is the final form of nitrogen that plants prefer for healthy growth.

— GUARANTEED ANALYSIS — F1144

Total Nitrogen (N)	18%
1.62% Ammoniacal Nitrogen	
2.46% Nitrate Nitrogen	
13.89% Urea Nitrogen	
0.03% Other Water Soluble Nitrogen	
Available Phosphate (P_2O_5)	18%
Soluble Potash (K_2O)	21%
Magnesium (Mg)	0.50%
0.50% Water Soluble Magnesium (Mg)	
Boron (B)	0.02%
Copper (Cu)	0.05%
0.05% Water Soluble Copper (Cu)	
Iron (Fe)	0.10%
0.10% Chelated Iron (Fe)	
Manganese (Mn)	0.05%
0.05% Chelated Manganese (Mn)	
Molybdenum (Mo)	0.0005%
Zinc (Zn)	0.05%
0.05% Water Soluble Zinc (Zn)	

Derived from Ammonium Sulfate, Potassium Nitrate, Urea, Soy Protein Hydrolysate, Monopotassium Phosphate, Sulfate of Potash, Magnesium Sulfate, Boric Acid, Copper Sulfate, Iron EDTA, Manganese EDTA, Sodium Molybdate, and Zinc Sulfate.

Information regarding the contents and levels of metals in this product is available on the Internet at http://regulatory-info-sc.com

Guaranteed Minimum Analysis

Total Nitrogen (N)	**20%**
Nitrate Nitrogen	12.1%
Ammoniacal Nitrogen	7.9%
Urea Nitrogen	0%
Available Phosphoric Acid (P_2O_5)	**8%**
Soluble Phosphorus	3.4%
Soluble Potash (K_2O)	**20%**
Soluble Potassium	16.6%
Calcium (Ca)	0%
Magnesium (Mg)	0.25%
Chelated Iron (actual) (Fe)	0.100%
Chelated Manganese (actual) (Mn)	0.050%
Chelated Zinc (actual) (Zn)	0.050%
Chelated Copper (actual) (Cu)	0.050%
Boron (actual) (B)	0.020%
Molybdenum (actual) (Mo)	0.015%
EDTA (chelating agent)	1.24%

Comparison between a couple of typical water soluble soil (left) and hydroponic (right) fertilizer labels.

The image above shows you a comparison between the labels for a water soluble soil and hydroponic fertilizer. In terms of NPK they both seem to be similar fertilizers, but the hydroponic fertilizer will have most of its nitrogen as nitrate while the other fertilizer has most of its nitrogen as urea. There are some other differences, mainly that the amount of phosphorous in the soil fertilizer is more than double that of the hydroponic fertilizer, which is also common given that phosphate is fixed rapidly in soil and therefore a higher excess is often added to ensure plants get enough supply. At an application of 1g/L the soil fertilizer would provide 75+ ppm of phosphorous while the hydroponic one would provide around 35. Also note that none of these two fertilizers would be enough to provide total plant nutrition since they both lack a source of Ca, which is commonly provided via a separate product in both cases.

So can any soil products be useful in hydroponics? Yes. First you need to completely avoid products that contain N mainly as urea or ammonium. Useful products to get for your hydroponic grow will be fully water soluble and will either contain nitrogen solely as nitrate or no nitrogen at all. A very coarse DIY formula can usually be put together using something like a micro nutrient containing 0-10-10 bloom fertilizer (which contains no nitrogen) coupled with a source of nitrate, like agricultural grade calcium nitrate. You can use Hydrobuddy – my open source hydroponic nutrient calculator – to figure out the nutrient contributions of each one of the products you decide to get or have easily available and create an acceptable formulation from their use. The program also contains a long list of readily available raw salts that you can use to make your own fertilizer formulations from scratch if you wish to do so.

In the end, soil products for home growers are not designed for hydroponics use and should therefore be avoided except as a last resort if raw salts or hydroponic specific nutrients cannot be purchased. If you're interested in saving money, learning how to prepare your own fertilizers from raw salts will always be the best and cheapest option, provided you have the time and desire to learn how to do it properly.