My pH Balancing System for Hydroponic Growing

In the past few days, several people have asked me how to use my carbonate/citrate buffering system as a means to control the pH of their nutrient solutions. For this reason, I decided to write a post which explains the simple way in which my buffering system can be prepared and a little more about how it works and what you can expect from it.

A pH buffer's function is to provide reaction "alternatives" for strong acids and bases when they contact the nutrient solution. These acid or basic substances generally react with water and this changes the value of pH. When a buffer is present, they react with the buffering molecules instead of water. This of course, makes pH remain approximately constant. Since the generation of species can be perfectly controlled and predicted by the use of mathematical methods, we can create very good buffering system by "experimenting" with different substances using a computer, as I mentioned in an earlier post.

As a result of my simulations I concluded that a mixture of citric acid/carbonate acts as a good buffer in hydroponics both towards the addition of acids and bases. The actual species involved are citrate and the bicarbonate ion, the bicarbonate ion reacts with acids, providing basic pH buffering, while the citrate reacts with acids providing an acid range buffering effect.

It is very easy to use this system by using your regular pH meter. Prepare your nutrient solution as usual, at the end, add 5g of citric acid for 500 liters of solution (this will acidify the pH of your solution a lot). Now, take back the pH to the value you want (5.8 to 6.2) by adding potassium carbonate. It is important not to use bicarbonate as this will react quickly with citric acid to form carbonic acid and then carbon dioxide (which will leave as a gas !). Also make sure you add both chemicals previously dissolved in water to afford quick chemical equilibrium achievement inside the solution.

By using this method you will have a nutrient solution that is perfectly buffered at your desired pH and that will remain at that pH value for a good amount of time. This of course, depending on the solution's volume and the type and number of plants you grow with it. (below, the distribution of species diagram or the carbonate family)

One Plant Hydroponic System, Wick Growing

Most hydroponic systems today are a fairly complicated combination of holding materials, irrigation systems, aeration pumps, etc. For most people wanting to grow a single plant in hydroponics it has become quiet impossible to figure out where to find a cheap system to do so.
One of the cheapest systems available for hydroponic gardening of small plants (ideal for experimentation and school projects) is the hydroponic wick nutrient system. This system uses an absorbent fiber to carry on nutrient solution by capillary action towards the plant which usually rests above it. Wick systems are very easily built and are a very good fit for the growing of small plants.
Medium sized and large sized plants start to have problems with hydroponic wick systems due to the inherent capillary flow limitations that physics impose on the flow of nutrient solution. The absorbent fibers on capillary systems are also often clogged because of nutrient salt buildup (due to water evaporation because of the large surface area of the fibers).

Water evaporation increases the concentration of salts along the fiber and starts to precipitate insoluble calcium and other metal phosphates. These are very hard to redissolve and often cause the system to stop working.

However, as I said before, wick systems such as the one built here are very appropriate for experimentation, growing a single hydroponic plant or doing school projects. The system is very easy and cheap to build.(below, a photograph of plants being grown on this system, note that they are very etiolated due to lack of proper lighting)

Outdoor Hydroponics, Growing Without a Greenhouse

Most hydroponic gardening techniques demand strict control over the growing media and ambient variables in order to have a crop in optimum conditions. However, most small hobby and commercial hydroponic gardeners do not have the budget necessary to build a greenhouse and need to have their systems exposed to the elements. This is why I decided to write a post about growing hydroponic plants in outdoor conditions, to show growers that hydroponics can be grown outside if adequate precautions are taken.
So what is the problem with the outdoors ? Well, the main problems are temperature changes, rain, haze, snow and excess light. Plants grown outside a greenhouse do not have any protection against direct sun, rain, haze or snow and are therefore most likely to be damaged by the elements. This of course, does not mean that the crops cannot be taken outside.
In countries where there are four seasons (and winter has snow), care needs to be taken not to grow any plants during the winter, because snow will most likely kill all the crops.

furthermore, low temperatures are likely to freeze the nutrient solution, something that can be a really bad problem in a hydroponic garden.

Another precaution that needs to be taken is to be specially watchful of the levels of EC in the hydroponics garden. In this special case, nutrients need to added in order to compensate for dilutions caused by rain. Electrical conductivity levels need to be taken before and after a rain storm in order to know the change in EC and return it to normal after. Note that this is a special case, normally nutrients should never be added to a solution which was naturally depleted by the plants. Please read the EC FAQ post for more information about this.

Another important thing is that plants should be protected from excessive evaporation by using hydro-gels. These polymers are applied over the plants root ball and effectively retain moisture for the plant so that possible stress from excessive evaporation becomes minimal. If the sun is too strong, additional measures such as nutrient reservoir cooling (with ice for example) have to be done in order to maintain adequate temperatures around the root zone.

It is clear that hydroponic crops can be grown outside but growers have to take special precautions with this area of hydroponics and commercial growers using this technique should have the losing of one crop a year in their budget (for crops such as lettuces) due to ambient conditions ruining their growth. (below, an image from a special program done by the UN to help poor people use hydroponics as a stable source of income)

Ion Selective Electrodes in Hydroponic Culture

Currently, hydroponic growers rely on a combination of electrical conductivity and pH measurements in order to assess the quality and durability of their hydroponic nutrient solutions. However, many are unaware that hydroponic gardening can be much furtherly enhanced by the addition of ion selective electrodes.

In a certain sense, all hydroponic gardeners have used an ion sensitive electrode since the pH meter they use to measure the concentration of $H_3O(+)$ ions is actually selective to that ion. Imagine if every time you read pH you had interference from all the other ions present inside the hydroponic solution. Nonetheless, there are currently a large variety of ion selective electrodes available and many of them can be used in hydroponic gardening to accurately control the concentration of several elements.

For example, ion selective electrodes with very good selectivity and little interference exist for the nitrate ion. These type of electrodes can be purchased from many manufacturers but can be easily found here. For just 229 USD, the grower is able to accurately control the amount of nitrate ions present inside the hydroponic solution independently from other nutrients.

By measuring the potential difference given by the electrode when the solution is prepared, the grower is able to easily detect and graph changes within a certain growing period. Best of all, since the ion selective electrode gives a real measure of ion concentrations, the grower is able to resupply spent nitrogen without unbalancing the hydroponic growing solution.

Ion selective electrodes exist for a variety of ions including nitrate, ammonia, phosphate, potassium, iron and copper. This technology will prove to be the future of hydroponics as it will guarantee the grower the ability to accurately control and resupply the exact amount of nutrients needed by his or her growing plants. These electrodes can also be easily wired to computer software in order to monitor nutrient use 24/7 (below a display of several ion selective electrodes)

Growing Citrus Trees in a Hydroponic Garden

While hydroponic gardening is most often done with plants like tomatoes, lettuce and bell pepper, it is well known that the hydroponic growing technique can be applied to a large variety of plants with different degrees of success. One type of plant that is an all time grower favorite is the citrus tree. Plants such as orange, lemon and mandarin (called citric because of their high citric acid content) can be grown effectively in a hydroponic garden.

Before you start your quest for a hydroponic citrus tree, beware that this type of plant demands somewhat warm weather and high amounts of light. These plants are not very good at indoor growing unless some LED growing lamps are used to complement lightning (although high pressure sodium and halide lamps can also be used).

Once you decide to grow a citrus tree the first step is to either find a suitable candidate from a nursery or grow your own from seed. If you want to grow from seed, beware that it will take the plant 3 to 5 years in order to start bearing fruit. If this is unacceptable, find a plant at a local nursery that has the age you require. If you are growing from seeds, soak the seeds inside a napkin for 2 days and then remove the external seed coating. This guarantees effective germination once the seed is planted.

For the best results, I recommend using a 5 gallon container filled with rice husk, perlite or vermiculite fitted with adequate tubing at the bottom for nutrient solution evacuation. I recommend installing a drip irrigation system with at least 3 drip emitters per citrus tree you planted.

As for the nutrient solution, I recommend using a Hoagland solution, first at half strength and then at full strength as the plant starts to grow. Your hydroponic citrus tree will not probably grow as big as an actual citrus tree but will bear fruit of normal size and sometimes even in the same quantities. Since your tree is in a hydroponics system, it will (if the solution is taken care of) never have to face any iron or manganese defficiencies common to soil grown citrus trees. Sometime in the next month I will publish a detailed how to on the construction of the hydroponic system itself.

Beneficial Fungi in Hydroponic Gardening

In common hydroponic culture, the growing media and the hydroponic nutrient solution are kept sterile in order to guarantee the absence of malicious plant pathogens. This however, changes the root environment dramatically and places plant roots in a media which is totally inert and different from the media in which they evolved, soil.
However, hydroponic gardening offers an important advantage in that adequate beneficial microorganisms can be cultured with our hydroponic plants, making the root environment change towards a much more soil-like beneficial media whith stimulated nutrient absorption, prevents pathogens and increases growth.

Amongst all the microorganisms that can be introduced into hydroponic media, none are as beneficial as the fungi commonly known as mycorrhiza. This term refers to fungi that create important symbiotic bonds with the plant’s roots, activating the plant’s internal defense mechanisms and boosting it’s nutrient uptake capabilities by using the fungus’s hyphae as nutrient uptake vehicles with a much higher surface are than common plant roots.

In practice, I have introduced Trichoderma species of fungi into my hydroponic solution every crop for the past 2 years with very good results. Trichoderma visibly stimulate the plant, making it vigorous and more productive than a traditional hydroponic plant. The fungi also increase the plant’s ability to assimilate phosphorous, something which is a problem where I live due to low ambient temperatures (which hinder P uptake). In order to use Trichoderma efficently in your hydroponic solution you should lower the amount of phosphorous under 40 ppm because higher amounts of this element inhibit the fungi’s development.

With this in mind I hope that all of you who have considered biological help in your hydroponic garden will start using these incredible microorganisms which are very good at helping your plants develop and maintain an adequate level of productivity. (Below a picture that shows the difference between plants with and without beneficial Trichoderma *spp* fungi)

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The NFT Hydroponic Growing System

In the last 50 years, many hydroponic systems have been developed in order to make crop cultivation easier, cheaper, faster and denser. Amongst the systems that have been developed, one of the hydroponic systems which has caught the most attention and is used more frequently is the so called NFT (Nutrient Film Technique) system.
The system's operation principles are quiet simple. A PVC (or or other polymer) rain gutter is placed on an aluminum frame with a certain inclination, plants are placed in small containers introduced inside the gutter and a nutrient solution is sprayed at the most elevated side of the gutter. The spraying forms a thin film on the gutter's bottom and flows towards the other end due to the slope.
The fact that the NFT system allows most of the plant's root system to remain outside the nutrient solution is the main reason for it's success. Throughout a lot of research, it has been found that plants just need to be "barely" in contact with the nutrient solution. Plant's seem to greatly benefit from their roots abosrbing oxygen from open air and taking just the little amount of necessary nutrients they need by a small contact with nutrient solutions.

The NFT system is great for crop cultivation and is one of the most efficient systems for the growing of crops such as basil, lettuce, spinach and cabbage. However it does have some disadvantages such as gutter length limitations due to nutrient and temperature changes (usually gutters are never more than 15 feet long), of course they also have the strong disadvantage of much higher costs (fue to the gutters being expensive) and lower planting densities (due to the spaces needed between gutters to allow personel). Nonetheless, many companies growing NFT systems have been able to make "foldable" gutters which allow automatic recollection of lettuce, transplanting and sterilization.

In conclusion, one could say that the NFT system is one of the best hydroponc growing systems that have been developed due to the fact that it allows greater oxygen and nutrient absortion. In fact, the hydroponic nutrient film technique is one of the most used systems for lettuce cultivation.

Disinfecting your Hydroponic Solution with Hypochlorite

As I talked about in a previous post, the disinfection problem in hydroponics is very important as many pathogenic microorganisms as well as algae develop through the course of any hydroponic gardening attempt. Hydrogen peroxide, as I said earlier, is a very good disinfectant with incredible properties but most of the time it is not used because of it's high cost.
Amongst one of the most common disinfectants available we find sodium hypochlorite. This chemical substance with formula NaClO is a good disinfectant because it oxidizes organic matter producing Cl_2 which then further oxidizes organic matter tu produce Cl(-). As you can see, the several steps available for oxidation as well as this compound's innate reactivity make it one of the best and cheapest disinfectants available today. This is the reason why sodium hypochlorite solutions have been used for a long time and now have commercial names, such as Clorox.
In hydroponics, sodium hypochlorite solutions are commonly used to sterilize a hydroponic system prior to use or in between different crops. However, this does not achieve the purpose of maintaining the nutrient solution sterile throughout the whole gardening cycle.

In order to achieve this in a very simple way (for the home hyroponic and commercial gardeners) several peer reviewed papers have studied the effect of hypochlorite ions on different plants and at different levels of concentration. In general, it has been found that concentrations of hypochlorite of 5.5 ppm offer good protection agains microorganisms without affecting the crop qualities.

If you do not have any industrial grade hypochlorite you can still achieve this concentration by applying 0.1mL of Clorox (check that it is less than 6% hypochlorite, usually 5.25%) per liter of nutrient solution. This can be easily measured and applied for small systems with the aid of a 1mL syringe as the ones diabetes patiens use for insulin (these syringes can be easily purchased at any pharmacy). Remember to try this with a small batch of plants before applying it over your whole garden to ensure compatibility with your particular nutrient solution.

Preparing Hydroponics Nutrient Solutions, From Concentrations to Weights

In a previous post, I explained how concentrations are given in hydroponic gardening and what they actually mean. For example, I exemplified that 200 ppm of N equals a solution which contains 200 mg per liter of nitrogen although the form in which nitrogen is present is not described by the concentration data. In this post, I intend to explain how nutrient concentrations can be translated adequately to a mass weight of a certain salt that will be the actual source of the nutrient.

Let us start by supposing that you have a certain solution recipe given in concentration data, for example, the solution demands 200 ppm N and 700 ppm K (this is just an example as 700 ppm of K is too high for any hydroponic nutrient solution). This means that the solution requires 200 mg per liter of nitrogen and 700 mg per liter of potassium. Our mission now is to translate this concentration information into the actual amount of a given salt that needs to be weight and dissolved.
The first thing we need to do is find a suitable salt or salts that can give us the nutrients we want in the appropiate forms. In this case, we will use potassium nitrate (KNO_3) as a source of both nitrogen and potassium. This salt gives the plant nitrogen as NO_3(-) ions and potassium as K(+) ions.

Our next step is to figure out how much solution we want to prepare. In this case, let's suppose we want to prepare 100L (around 32 gal) of nutrient solution.

Following this, we must calculate how much much K(+) and how much NO_3(-) need to be added in order to achieve the concentrations we desire. Since K(+) contains a single K atom, we need 700 mg/L of K(+) in order to achieve 700 ppm of K, for the nitrate ion (NO_3(-)), since it contains more atoms, we need to know how much of the nitrate ion is actually nitrogen. In order to do this we calculate what fraction of nitrogen resides in nitrate by relating their molar mases (you can google nitrate molar mass and nitrogen molar mass to get this values or calculate them using your periodic table) . The calculation would be 14/62 which equals 0.22. This means that 22% of each nitrate ion is nitrogen. If 22% of each nitrate ion is nitrogen then we need 200ppm x(100/22) of nitrate in order to get the concentration of nitrogen we want. The result is that we need 909 mg of nitrate per liter in order to achieve our required concentration of 200 ppm.

Since our salt is KNO_3 and not K or NO_3 by themselves we need to decide which nutrient we want to fit in an exact manner. For this example I will take NO_3(-). Since we want to weight

909mg per liter of $NO_3(-)$ we see how much KNO_3needs to be weight in order to achieve this amount for 100 liters. For this we use the relationship between the molar mases of nitrate and the salt, potassium nitrate. The equation is 62/101, which equals 0.61, meaning 61% of potassium nitrate is nitrate. Since we want to know how much is 100% knowing that 61% is 909mg per liter we calculate 909ppm x 100/61, which equals 1490mg per liter which needs to be multiplied by 100 in order to find the amount needed for 100 liters of solution. The final result is that 149 g of potassium nitrate are needed in order to achieve a concentration of 200 ppm of N in 100 liters of solution.

Now what happened to the potassium ? Since we added potassium nitrate, we also added potassium with the salt. We now need to calculate the concentration of potassium which we get when we arrive at a concentration of 909 ppm for ntirate. Since we know nitrate is 61%, then potassium must be 39% of the concentration so 1490 ppm x 0.39 equals 581 ppm.

As you can see, we matched our nitrogen requirement perfectly but ofset our potassium requirement by an important amount. This problem is due to the fact that each salt gives two nutrients to a soltuion. Meaning that a good salt combination needs to be used in order for our errors to be reduced when preparing the hydroponic nutrient solutions. This problem can be solved by using the hydroponic nutrient solution calculator I described in an earlier post, however, it is important to know how the calculator works in order to understand its possible errors.

As you can see, preparing nutrient solutions and turning concentrations into weights can be a little bit daunting at first but with practice and the aid of calculator tools, the preparation of custom hydroponic solutions becomes very easy and paves the way towards major improvements for any commercial or hobbyst hydroponic gardener.

Describing Concentration in Hydroponics

Most amateur growers, both hobby and commercial, who do not have a chemical knowledge background are most of the time stunned by the amount of chemistry involved in hydroponic cultivation. One of the things that proves to be the most difficult for this new comers is the understanding and description of nutrient concentrations.
Concentration, to start, is just a way of expressing the amount of something inside something else. In hydroponics, we are interested in expressing the amount of nutrients per amount of nutrient solution. To do this, we use several tools available in chemistry.

In general, concentrations in hydroponics are either expressed as moles of nutrient per liter of solution or as milligrams of nutrient per liter of solutions. The first unit is called molarity while the second unit is generally referred to as ppm (parts per million). This means that a solution containing 12 ppm of Nitrogen contains 12mg of nitrogen per liter of solution and a solution containing nitrogen in a 0.001M concentrations contains 0.001 moles of nitrogen per liter of solution. The first form of concentration (ppm) is often used in hydroponics while the second (M) is used in hydroponics only in research papers and such.

In practice, the use of concentrations in ppm makes preparation a little bit easier as the leap from concentration to mass becomes easier if the unit of measurement inside the unit belongs to mass. Since the ppm unit can be translated as (mg/L) going to the mass of salt required is easier than with molarity (although not by much).

Another advantage that we come across when using ppm as a main unit of concentration measurement in hydroponics is that the numbers are likable. We, humans, tend to like numbers between 0 and 1000, so concentrations of 120 ppm, 250 ppm and such, seem much easier to grasp than their equivalents in molarity which would be 0.0012 M, 0.00023 M or the like.

In an article to be written soon, I intend to describe how to do the leap from this concentration measurements onto the mass of salt that is needed to weight in order to achieve the desired concentration inside a hydroponic solution. So stay tuned to know a little bit more about the science of hydroponic nutrient solution making !