Common questions about silicon in nutrient solutions

Introduction

We know that silicon can be a very beneficial element for many plant species (see some of my previous posts here and here). It mainly enhances disease resistance and increases the structural integrity of plant tissue. Because of these advantages, you will want to add silicon to your nutrient solution. However, there are a lot of misconceptions and questions about the use of Si in plants and the exact form of Si that you should use. In this post I am going to address some of the most common questions about silicon sources and how to use them properly.

Alkali metal silicates are the most common sources of soluble silicon used. They also have the lowest cost by gram of Si.

What sources are available?

To use silicon in nutrient solutions, we will generally have 3 types of sources available.

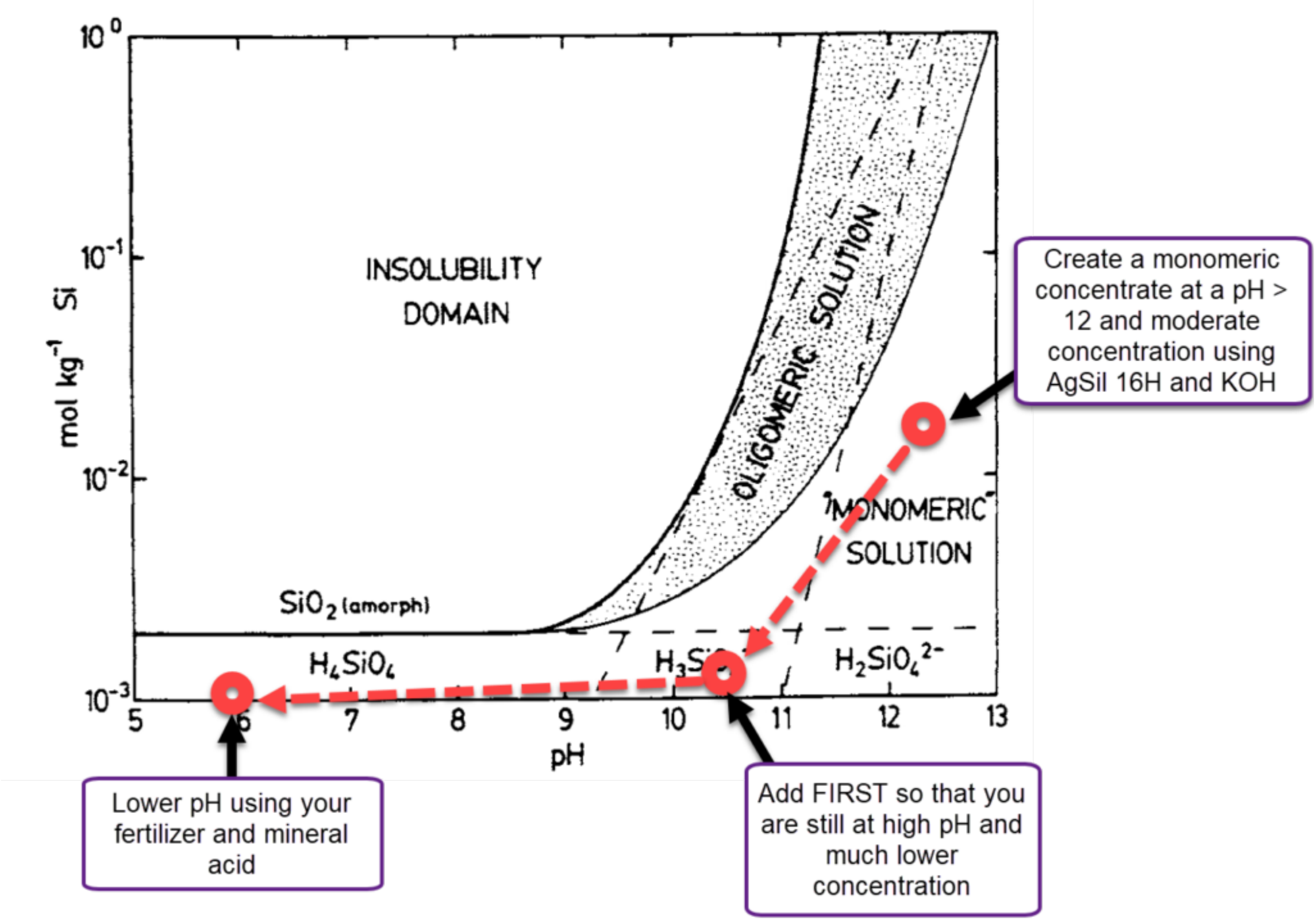
First, we have **basic potassium silicates**, which are solids or solutions derived from the reactions of silica with potassium hydroxide. In this category you have popular products like AgSil 16H and liquid concentrates like Growtek Pro-Silicate. These products have a very basic pH.

Second, we have **acid stabilized silicon products**. These are products like PowerSi Classic and OSA28. These products are always liquids and contain monosilicic acid in an acidic environment, with stabilizing agents added to prevent the polymerization of the monosilicic acid.

Third, we have **non-aqueous products with organosilicon reagents**, like Grow-Genius. These products do not contain water and are derived from reagents like TEOS (tetraethyl ortho-silicate) and other Si containing compounds, mainly Si containing surfactants. They are not in forms that are plant available but will generate these forms when in contact with water.

Do potassium silicates contain "less available" silicon?

When you dissolve a potassium silicate at high concentration, it forms silicate oligomers. These are large silicon chains that get stabilized in basic solutions because of their high negative charge. This is why you can create highly concentrated potassium silicate solutions in basic pH. As a matter of fact, making the solutions more basic with added potassium hydroxide often enhances the solubility of potassium silicate solids like AgSil16H (see here for a procedure on how to do this). However, when the molar concentration decreases the silicate hydrolyzes into monomeric silicate anions.



Create a monomeric concentrate at a pH > 12 and moderate concentration using AgSil 16H and KOH

Lower pH using your fertilizer and mineral acid

Add FIRST so that you are still at high pH and much lower concentration

Original background image taken from here. To create a monomeric solution you need high pH and low concentration. Then you lower the pH to get to monosilicic acid.

When potassium silicate is diluted in nutrient solutions, this is exactly what happens. The reduction in concentration hydrolyzes the Silicates into monomers. If the solution pH is *then* lowered, the final form present will be monosilicic acid. If you properly prepare a nutrient solution with potassium silicate, the end form will be monosilicic acid, the form that is mostly available to plants.

It is a misconception that potassium silicates are somehow less "plant available". They end up producing monosilicic acid and being perfectly available, when used properly.

How do I properly use a potassium silicate?

First, if using a solid, you need to prepare a stock solution no more concentrated than 45g/L. The recommendation with AgSil 16H would be to prepare a stock solution at 15g/gal and then using this solution at a rate of 38mL/gal of final solution (injection rate of 1%). To increase the stability of your AgSil 16H concentrate you can add 1g/gal of KOH. The end addition to your solution will be +9.8ppm of Si as elemental Si and +11.55ppm of K. The KOH addition and low 15g/gal concentration ensures that silicate will already be largely present as monomeric silicate anions.

Second, make sure to add this solution to your water first. If you add this solution after nutrients, the Si will come into contact with Ca and Mg in its concentrated form, which will cause problems with its stability in solution. Add it first, then add your lowest pH fertilizer concentrate, then your Ca containing concentrate, then finally decrease the pH with an acid to the desired level if needed.

This procedure ensures you get a final solution containing monosilicic acid that will be stable. If you increase the Si in the stock solution, change the injection order, or increase the Si in the end solution beyond 20ppm of Si as elemental Si you might end up with precipitated and unavailable Si forms.

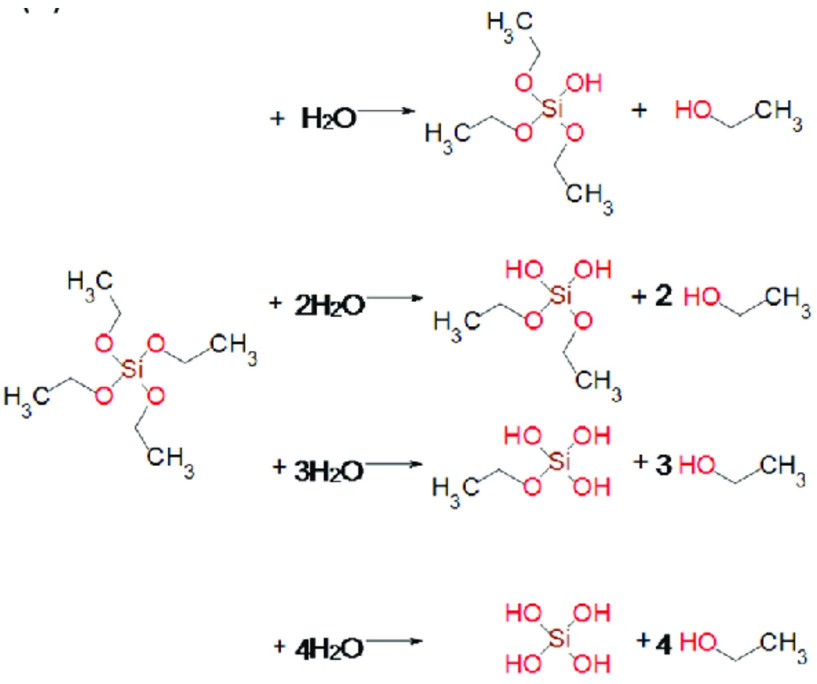
Why would you use acid-stabilized Si products?

Acid stabilized silicon sources are *not* more plant available. However, their starting pH is usually low and their mineral composition can also be minimal (depending on the preparation process). This means they can lower the need for acid additions and can help lower the pH of hard water sources when used. They can also contain stabilizing agents that could be beneficial for plants. However, the exact stabilizers used and the exact mineral composition used will vary substantially by product, since there are a wide array of choices available to manufacturers.

In the end, at the pH where plants are fed, acid stabilized Si and potassium silicate sources generate the exact same monosilicic acid. **Plant availability is *not* an advantage of using this sort of product**.

Why would you use non-aqueous Si products?

These products can be much more highly concentrated than either basic silicon or acid stabilized liquid silicon products by mass. This is because they are made from Si forms that are highly stable under water-free conditions. This means you can buy a small amount and add a small amount to your reservoir per gallon of solution prepared. Another advantage is that they are pH neutral and do not alter the pH of nutrient solutions at all. The formation of the silicic acid from these products requires only reactions with water, so no mineral addition, stabilizer additions or pH modifications happen.



Reaction of TEOS with water to produce different silicic acids (plus ethanol)

A significant point however is that the reaction of a product like TEOS with water releases other substances into solution. *For each 10 ppm of Si as elemental Si that you add from TEOS you will in fact be adding ~66pm of ethanol to your solution*. These alcohols can be very detrimental for root and plant growth, reason why the use of these non-aqueous Si products needs to be carefully considered. When using a product containing non-aqueous Si sources, it’s important to consider that these substances can accumulate in your root zone and may cause problems. Which organics are present and whether they will cause problems will depend on the exact formulation. **When using these organosilicon sources, passing the nutrient solution through a carbon filter to remove these organics before contact with plant roots would be ideal.**

Is the final Si in solution from any product type more stable?

No, all three types of products, when used properly, will end up as stable monosilicic acid in your solution. The stabilizing agents in acid-stabilized products will be so dilute that any additional stabilizing effect will be relatively non-existent. If Si is dilute enough (<20ppm of Si as elemental Si), then it will be stable in solution indefinitely (I measured 5 weeks with no changes in concentration). At higher Si concentration, the Si will tend to polymerize (no matter which source it comes from) which will create problems with stability. To have stable Si in solution make sure that you prepare it properly and that you keep the concentrations low enough.

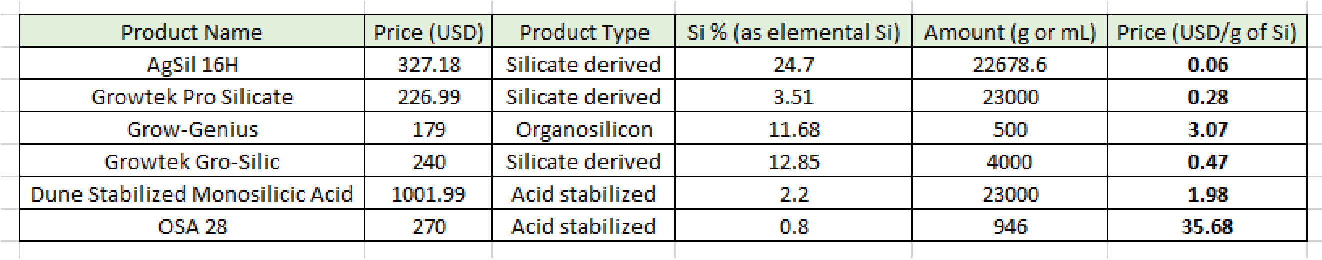
If they are mostly the same in terms of Si availability, why do I see differences between different products at an equivalent Si application rate?

Despite all of the different Si products leading to the same form of Si in the final solution, acid-stabilized Si products will contain a wide array of additional substances that are going to be active nutritionally. For example, Boron and Molybdenum are very commonly used stabilizing agents. Products, like PowerSi bloom, also contain “exotic plant extracts” (according to their website). Commonly used stabilizing agents include glycerol, carnitine, choline and sorbitol. All of these could potentially have an effect on the plants at the concentrations added with these products. Some of these stabilizing agents are usually added at 10-50x the amount of Si present by mass, meaning that your Si supplement might be adding way more of these stabilizing agents than what you’re adding in terms of Si.

What product is more cost effective per delivered mole of monosilicic acid?

There is a lot of space in labeling regulations to allow fertilizer manufacturers to trick people into believing a product might be more concentrated or dilute than another. First of all, labeling a product as “% of monosilicic acid” does not mean that the product contains that percentage of monosilicic acid, it means that the product contains Si, such that if that silicon was all converted to mono-silicic acid, it would give that percent. The only products that contain monosilicic acid in its actual form from the start are acid-stabilized Si containing products, which are usually limited to low concentrations due to the reactivity of this molecule when present.

Both non-aqueous silicon products and soluble potassium silicate products contain precursors to monosilicic acid. One in the form of organosilicon compounds and the other in the form of silicate chains. As mentioned above, both precursors can lead to very high conversions to mono-silicic acid when properly used.



Product Name	Price (USD)	Product Type	Si % (as elemental Si)	Amount (g or mL)	Price (USD/g of Si)
AgSil 16H	327.18	Silicate derived	24.7	22678.6	**0.06**
Growtek Pro Silicate	226.99	Silicate derived	3.51	23000	**0.28**
Grow-Genius	179	Organosilicon	11.68	500	**3.07**
Growtek Gro-Silic	240	Silicate derived	12.85	4000	**0.47**
Dune Stabilized Monosilicic Acid	1001.99	Acid stabilized	2.2	23000	**1.98**
OSA 28	270	Acid stabilized	0.8	946	**35.68**

These prices were the lowest prices I could find for each product in Feb 2023. To find current prices, I suggest searching any products you’re interested in. Composition values taken are those provided by the manufacturer, converted to Si as elemental Si. Prices do *not* include shipping.

To compare the actual concentration of products, it is best to always convert the amounts to elemental Si percentage values.

To convert monosilicic acid % values to Si, multiply the value by 0.2922, to convert SiO_2 values to Si, multiply the value by 0.4674. For example, 40% Si as monosilicic acid is equivalent to 11.68% Si as elemental Si. Soluble potassium silicates like AgSil 16H can be around ~24% Si as elemental Si by mass, making them the most highly concentrated and lowest cost form of bioavailable silicon when used properly. More highly soluble potassium silicates than AgSil16H will usually be lower in Si, as higher K proportions lead to better solubility and a lesser need to add KOH when preparing stock solution. The table above, showcases the price differences per gram of Silicon of different products as of Jan 2023. **When purchased in bulk (50 lbs) AgSil16H can be up to two orders of magnitude lower cost than other alternatives.**

I have done lab tests measuring molybdenum reactive Si that show all the Si in AgSil16H can be quantitatively converted to monosilicic acid when following the preparation guidelines mentioned in this post.

What is your recommendation?

After studying the subject for years, using different products with different growers and testing the chemistry myself (preparing stabilized silicic acids and measuring active Si concentrations). Given the price of Si products and the chemistry involved, I would suggest anyone interested in Si supplementation in nutrient solutions to use a potassium silicate solid product. I would suggest to prepare a suitable stock with potassium silicate and potassium hydroxide to increase pH and stability and then prepare their nutrient solutions from dilutions of this stock. If a solid product like AgSil 16H is not available, then using a basic silicate concentrate product would be the next best choice. Usually preparing a more dilute stock from these products is recommended to ensure the stock already contains monomeric silicate.

I don’t think acid-stabilized silicon products or non-aqueous Si products are worth the price premium. If you’re having better results with a non-potassium silicate product compared to potassium silicate, bear in mind that this is likely because either the potassium silicate stock preparation and dilution were not done correctly or the product you’re using contains a substance different from Si that is giving you those effects. The stabilizing agents themselves are going to be much lower cost, so testing the eliciting effects of these agents might be more economical for you than using these expensive products long term.

In cases where mixing stocks and handling basic reagents is problematic or there is limited availability to adjust pH, then the use of non-aqueous Silicon reagents might be desirable. Non-aqueous silicon forms are also the most robust to mixing errors – wrong mixing order, mixing at variable pH, etc – because the hydrolysis reactions happen readily under a wide variety of conditions. However, my recommendation is to always couple these with carbon filtration to avoid potential issues from their organic side-products.

If you have issues with the use of soluble silicon sources – because of your initial water composition, injector limitations, cost, etc – and your media supports amending, I would also suggest considering using solid amendments to supplement Si (watch this video I made for more information). Amending can be a great choice, much more economical than soluble Si supplementation.

Do you have any questions about Si in nutrient solutions not addressed above? Feel free to leave a comment and I might also add it to the post!

Connecting a low cost TDR moisture content/EC/temp sensor to a NodeMCUv3

I have discussed moisture content sensors extensively in the past. I have written posts about the use of capacitive moisture sensors to measure volumetric moisture content, including how to create sensor stations and how to calibrate them. However, while capacitive moisture content sensors can be a low cost alternative for low resolution monitoring of moisture content, more precise applications require the use of higher accuracy sensors, such as Time Domain Reflectometry (TDR) sensors. In this post I am going to show you how to connect a low cost microcontroller (NodeMCUv3) to a low cost TDR moisture content sensor. *Note, some of the product links below are amazon affiliate links, which help support this blog at no additional cost to you.*

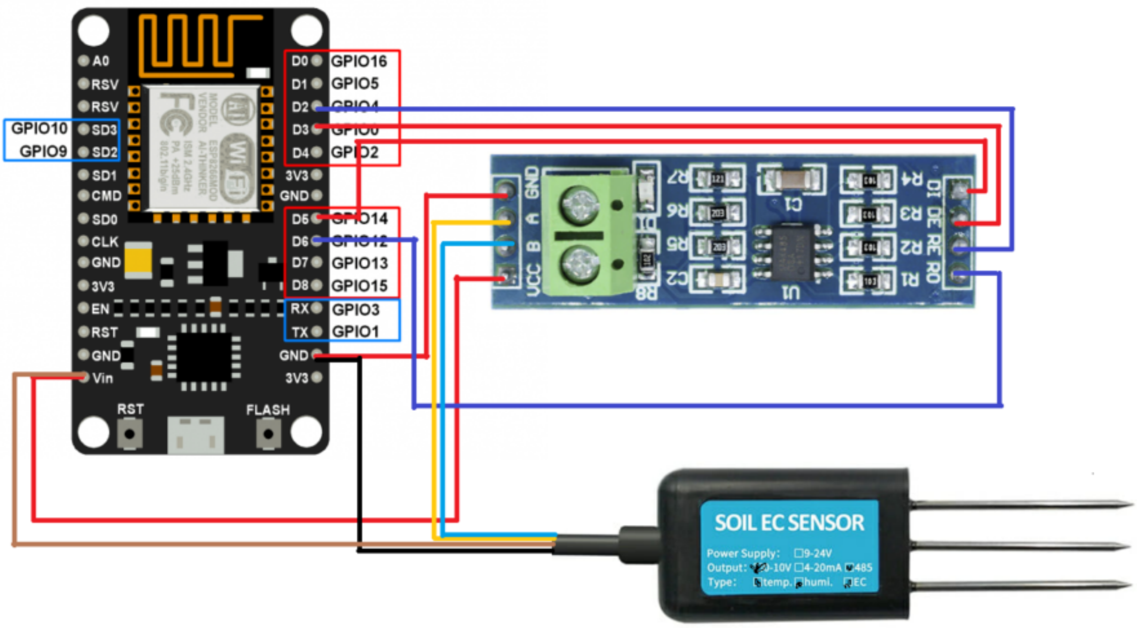


Diagram showing cable connections between moisture content sensor NodeMCUv3 and communication board.

While popular sensors like Teros-12 sensors cost hundreds of dollars, lower cost alternatives have been created by Chinese manufacturers. Using this github repository by git user Kromadg, I have been able to interface some of these low cost TDR sensors with a NodeMCUv3. The NodeMCUv3 is a very low cost microcontroller unit that you can get for less than 5 USD a piece. It is also WiFi enabled, so this project can be expanded to send data through Wifi to use in datalogging or control applications. For this project you will need the following things:

1. Micro USB cable
2. NodeMCUv3
3. THC-S RS485 sensor (Make sure to get the THC-S model)
4. TTL to RS485 communication board
5. Breadboard and jumper cables to make connections or cables and a soldering kit to make final connections.

The above diagram shows you how to connect the sensor, TTL-to-RS485 communication board and the NodeMCUv3. You will also want to make sure you install the ESP Software serial library in your Arduino IDE, as the normal Software Serial library won’t work. You can do this by downloading the zipped library from github and then using the Sketch->Include Library menu option. Once you do so, you can upload the following code into your NodeMCUv3.

```
#include <SoftwareSerial.h>
#include <Wire.h>

// This code is a modification of the code found here
(https://github.com/kromadg/soil-sensor)

#define RE D2
#define DE D3

const byte hum_temp_ec[8] = {0x01, 0x03, 0x00, 0x00, 0x00,
0x03, 0x05, 0xCB};
byte sensorResponse[12] = {0x00, 0x00, 0x00, 0x00, 0x00, 0x00,
0x00, 0x00, 0x00, 0x00, 0x00, 0x00};
```

```
byte sensor_values[11];

SoftwareSerial mod(D6, D5); // RX, TX

void setup() {
    Serial.begin(115200);
    pinMode(RE, OUTPUT);
    pinMode(DE, OUTPUT);
    digitalWrite(RE, LOW);
    digitalWrite(DE, LOW);
    delay(1000);
    mod.begin(4800);
    delay(100);
}

void loop() {
    /************** Soil EC Reading ******************/
    digitalWrite(DE, HIGH);
    digitalWrite(RE, HIGH);
    memset(sensor_values, 0, sizeof(sensor_values));
    delay(100);
    if (mod.write(hum_temp_ec, sizeof(hum_temp_ec)) == 8) {
        digitalWrite(DE, LOW);
        digitalWrite(RE, LOW);
        for (byte i = 0; i < 12; i++) {
            sensorResponse[i] = mod.read();
            yield();
        }
    }

    delay(250);

    // get sensor response data
     float soil_hum = 0.1 * int(sensorResponse[3] << 8 | sensorResponse[4]);
     float soil_temp = 0.1 * int(sensorResponse[5] << 8 | sensorResponse[6]);
     int soil_ec = int(sensorResponse[7] << 8 | sensorResponse[8]);

     /************* Calculations and sensor corrections
```

```
*************/

    float as_read_ec = soil_ec;

    // This equation was obtained from calibration using
distilled water and a 1.1178mS/cm solution.
    soil_ec = 1.93*soil_ec - 270.8;
    soil_ec = soil_ec/(1.0+0.019*(soil_temp-25));

    // soil_temp was left the same because the Teros and
chinese sensor values are similar

    // quadratic aproximation
    // the teros bulk_permittivity was calculated from the
teros temperature, teros bulk ec and teros pwec by Hilhorst
2000 model
    float soil_apparent_dieletric_constant = 1.3088 + 0.1439 *
soil_hum + 0.0076 * soil_hum * soil_hum;

                  float soil_bulk_permittivity =
soil_apparent_dieletric_constant;  /// Hammed 2015
(apparent_dieletric_constant is the real part of permittivity)
    float soil_pore_permittivity = 80.3 - 0.37 * (soil_temp -
20); /// same as water 80.3 and corrected for temperature

    // converting bulk EC to pore water EC
    float soil_pw_ec;
    if (soil_bulk_permittivity > 4.1)
        soil_pw_ec = ((soil_pore_permittivity * soil_ec) /
(soil_bulk_permittivity - 4.1) / 1000); /// from Hilhorst
2000.
    else
        soil_pw_ec = 0;

    Serial.print("Humidity:");
    Serial.print(soil_hum);
    Serial.print(",");
    Serial.print("Temperature:");
    Serial.print(soil_temp);
    Serial.print(",");
    Serial.print("EC:");
```

```
    Serial.print(soil_ec);
    Serial.print(",");
    Serial.print("READEC:");
    Serial.print(as_read_ec);
    Serial.print(",");
    Serial.print("pwEC:");
    Serial.print(soil_pw_ec);
    Serial.print(",");
    Serial.print("soil_bulk_permittivity:");
    Serial.println(soil_bulk_permittivity);
    delay(5000);
}
```

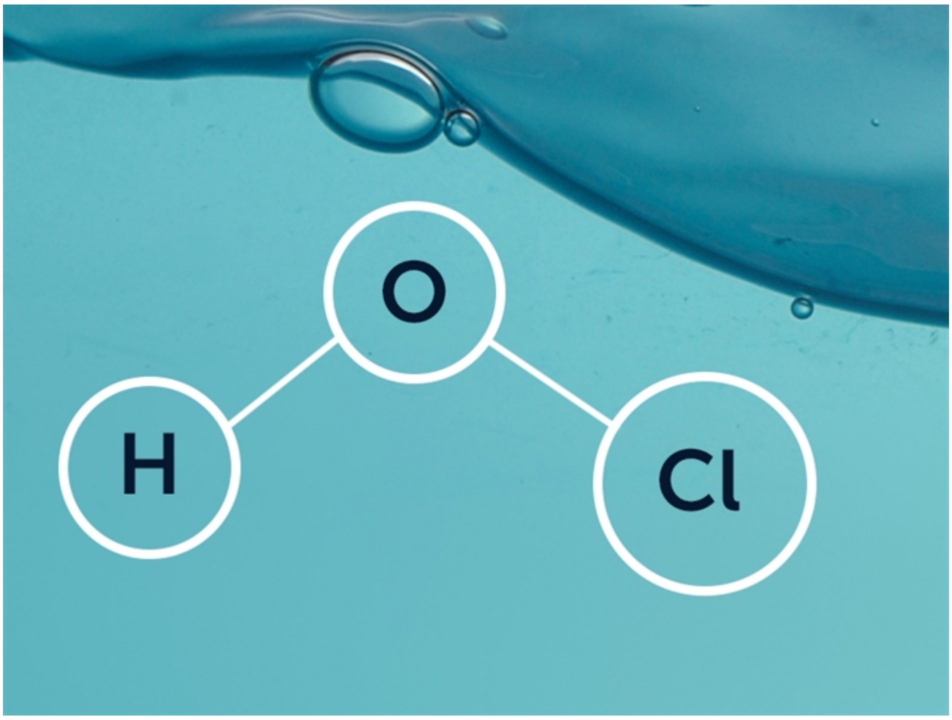
Note that RE and DE are not placed on digital pins 2 and 3, as other pins in the NodeMCUv3 carry out other functions and the board will not initialize if it has the RS485-to-TTL communicator connected through those pins. The R0 and RI pins are connected to digital pins D5 and D6, this is because in the NodeMCUv3 pins D7 and D8 are used in serial communication by the Serial swap command and therefore create conflicts if you use them with SoftwareSerial. The above digital pin distribution is one of the few that works well. Note that connecting RE or DE to digital pin 4 also works, but this means the blue LED on the NodeMCUv3 is powered on every time there is serial communication, a potentially undesirable effect if you’re interested in battery powering the device.

The board should now be printing all the measurements on your serial connection, so you should be able to see the readings through the Serial Monitor in the Arduino IDE. In the future I will be sharing how to expand this code to include WiFi and MQTT communication with a MyCodo server.

If you use this code please share your experience in the comments below!

How to prepare your own hypochlorous acid cleaner using bleach

During the past couple of years, cleaning products based on hypochlorous acid derived from electrolysis have become popular in the hydroponic industry. This is because, in the USA – per 40 CFR § 180.940 – hypochlorous acid products containing less than 200 ppm of active chlorine are exempted from many manufacturing and handling requirements and are therefore easy to produce and dispense to hydroponic growers. While more dilute, the formulations produced can often be much more stable than more concentrated products and still provide satisfactory cleaning results in a hydroponic reservoir. However, the products carry a lot of additional cost compared to traditional sodium hypochlorite based cleaning products. This is because more needs to be used – as they are more dilute – and the products themselves are often much more expensive.



Graphic representation of hypochlorous acid

In this post, I want to help you create a solution analogous to many commercially available, electrolytically derived hypochlorous acid cleaners, using products that are easily available and low cost. The resulting solution is – for all intents and purposes I can think of – equivalent to electrochemically derived hypochlorous acid, since the hypochlorite ion becomes protonated at low pH, generating the required substance during the preparation process. To create this formulation, I relied on the following documents and the scientific literature they referenced (1, 2, 3).

Important note. *Hypochlorous acid is unstable in highly concentrated solutions. Increasing the concentration of the formulation below significantly can lead to potentially dangerous releases of chlorine gas when the pH is lowered. Work in a well ventilated area and do not exceed the concentration amounts recommended in this preparation. Work responsibly and make sure to read all the MSDS of the substances used and use appropriate personal protection equipment.*

These are the things you will need for the preparation :

1. Freshly bought Clorox (7.4%). The solution should not be older than one week.
2. A 20 mL syringe.
3. Monopotassium Phosphate (MKP).
4. Sodium Chloride (table salt will do).
5. Magnesium Sulfate.
6. Sodium Tripolyphosphate.
7. A calibrated pH meter.
8. A scale to weigh salts, +/-0.1g.
9. A scale to weigh water +/-0.1kg
10. Distilled or RO water (tap water will not work). Distilled is preferable.
11. Clean plastic, air-tight container (at least 1gal) to store the resulting solution. The container should be

opaque.

This is the procedure you should follow for the preparation of the hypochlorous acid solution (values for ~1.2 gallon, can be scaled up for larger amounts):

1. Calibrate your pH meter using fresh pH 4 and pH 7 buffer solutions.
2. Fill the container with 3.6 kg of distilled water, this will be referred to as the solution.
3. Weigh and add 0.5g of Sodium Chloride to the solution.
4. Stir until fully mixed.
5. Weigh and add 0.1g of Sodium tripolyphosphate to the solution.
6. Stir until fully mixed.
7. Measure 11mL of Clorox and add it to the solution. If you’re working with a bleach solution with concentration other than 7.4%, multiply 11mL by 7.4 and divide by your concentration to obtain the amount you should use in mL (for example, if using a 6% bleach solution, you would require 11*7.4/6 = 13.56mL).
8. Stir until fully mixed.
9. Weigh 0.5g of Monopotassium phosphate and add to the solution.
10. Stir until fully mixed.
11. Measure the pH of the mix. If the pH is >7 slowly add and fully mix small portions (~0.1g) of monopotassium phosphate until the pH is in the 6.5-7 range. Take at least 1 minute between additions to ensure the pH has stabilized before adding more.
12. Weigh and add 3.5g of Magnesium sulfate to the solution
13. Stir until fully mixed.
14. Add 0.9kg of water.
15. Confirm final pH is in the 6-7 range, you can add more monopotassium phosphate if needed to drop the pH.

This should provide you with a solution that is stable in the medium term and has the active chlorine concentration of a formulation similar to products like Athena Cleanse. The expected concentration of hypochlorous acid should be around 0.02% (200ppm). It can be used from 2 to 10mL/gal of hydroponic nutrient solution, depending on the severity of the problems that need to be solved. *For overall maintenance and the solution of minor infections, dosages of 5mL/gal should be more than adequate*. The Magnesium Sulfate and Sodium Chloride are added as stabilizing agents, while the mono potassium phosphate is added as a pH buffering agent and the sodium tripolyphosphate is a cleaning agent meant to keep irrigation lines clean (it can be omitted if this is not a concern). *Note that the contributions of the mineral ions to a formulations nutrition at the applied concentrations are negligible.*

Please do let me know if you have any questions about the above preparation. **If you have prepared it, please let us know how it went in the comments below!**

A cost analysis of fertilizers for hydroponic/soilless growing in 2022

Why fertilizer costs matter

Fertilizer can be one of the largest expenses of a hydroponic growing facility. This is especially true when boutique fertilizers are used, instead of large scale commodity fertilizers. The use of non-recirculating systems with high nutrient concentrations also contributes heavily to high cost fertilizer usage. A medium scale growing facility working with boutique fertilizers can in some cases spend 2000-4000 USD per day. Even when using some of the most cost effective solutions, a facility can still spend 4000 USD per day if they use 20,000 gal/day with a nutrient line costing 0.2 USD/gal.

The above is a common combination of raw inputs and a standard blended input

In 2022, the high cost of energy and high inflation have increased raw fertilizer input costs to the highest point of the past decade, making the problem of fertilizer costs even more pressing. This has been specially the case for soluble phosphate fertilizers which have, in some cases, seen costs triple from the start of 2019. This is because soluble phosphates were largely produced in Russia and alternative sources of soluble phosphates had a hard time ramping up capacity at the same cost level as could be previously achieved.

To help people who are growing better assess their costs, I seek to paint a clear picture of the current cost level of commodity and boutique fertilizers as well as the cost levels that can be achieved with preparation of custom solutions.

Price sources

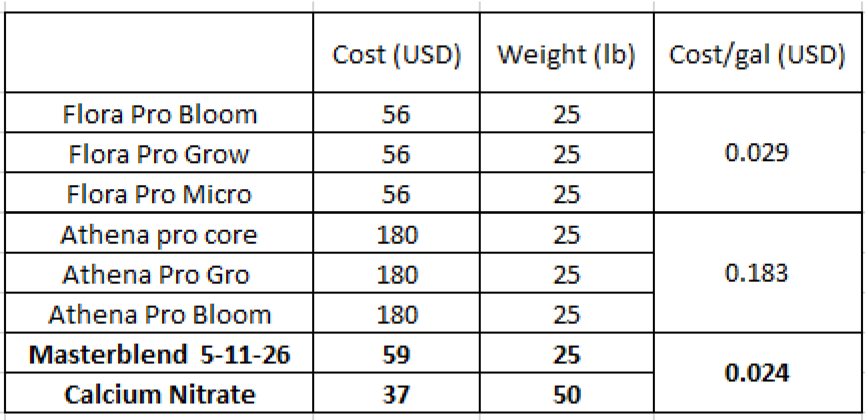
The cost analysis focuses on the US market. The prices I obtained for boutique fertilizers are from google searches where I found the cheapest costs at the highest scale I could find. For commodity fertilizers I used the price points of customhydronutrients.com, which is a trust-worthy website for the purchase of fertilizer inputs. These prices are also accessible from small to large scales, so they do not require large scales to be accessible. Boutique fertilizer companies might offer larger discounts to people who contact them directly to buy large amounts, but I did not use these prices as they are not publicly available.

To make comparisons easier, I will express all costs as costs per final gallon of nutrient solution, when prepared per the directions of the manufacturer or to arrive at formulations with a reasonable composition (formulations that can grow healthy, high yield crops). Please also note that I only considered fertilizers that could be used to prepare concentrated solutions to be used for injection, as these are fundamental to large scale growing operations. I also only considered powdered fertilizers as these offer the lowest cost. Liquid concentrated fertilizers – which are often substantially more expensive – were not considered.

For purposes of keeping the costs as low as possible I also only considered the base products from boutique fertilizer companies and did not consider the costs of any of their additives (line cleaners, boosters, hormones, etc). Shipping costs are also *not* considered here.

Blended fertilizers

The easiest, most accessible fertilizers for most people will be pre-blended fertilizers. Due to the proliferation of the cannabis industry, most of the pre-blended fertilizers that are sold to retail growers will be cannabis-centric and will have a considerably higher price than the blends currently used by the wider hydroponic industry.



	Cost (USD)	Weight (lb)	Cost/gal (USD)
Flora Pro Bloom	56	25	0.029
Flora Pro Grow	56	25	
Flora Pro Micro	56	25	
Athena pro core	180	25	0.183
Athena Pro Gro	180	25	
Athena Pro Bloom	180	25	
Masterblend 5-11-26	**59**	**25**	**0.024**
Calcium Nitrate	**37**	**50**	

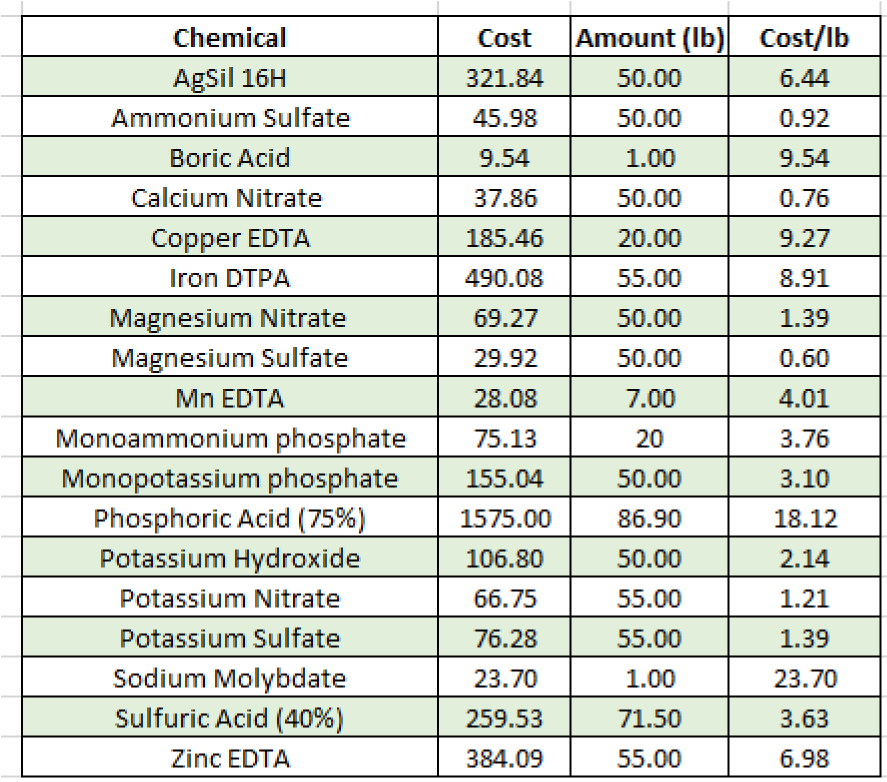
Table comparing a couple of boutique lines with a standard 5-11-26 preparation using a Masterblend product and Calcium nitrate.

The table above shows three representative fertilizer programs for comparison. The Flora Pro series from General Hydroponics was the lowest cost boutique fertilizer I could find, with a total cost of 0.029 USD per gallon at the recommended dosing rates by General Hydroponics. I also put the Athena line for comparison, as they often portray themselves as a low cost option for cannabis companies. Their cost is almost an order of magnitude higher, at 0.183 USD/gal. From this analysis it seems clear that their margins are much higher than those of General Hydroponics although they can be substantially more cost effective than other companies with even more expensive products.

After seeing the above table, it is clear that boutique companies are not price competitive against formulations using traditional blended fertilizers from the agricultural industry. A formulation using Masterblend 5-11-26 and Calcium nitrate, which could be perfectly adequate for the growth of flowering plants during their vegetative stage or purely vegetative plants like basil, has a cost of 0.024 USD/gal. Similar simple approaches using other blended products can be used to achieve a variety of compositions at a similar price tag.

Raw input fertilizers

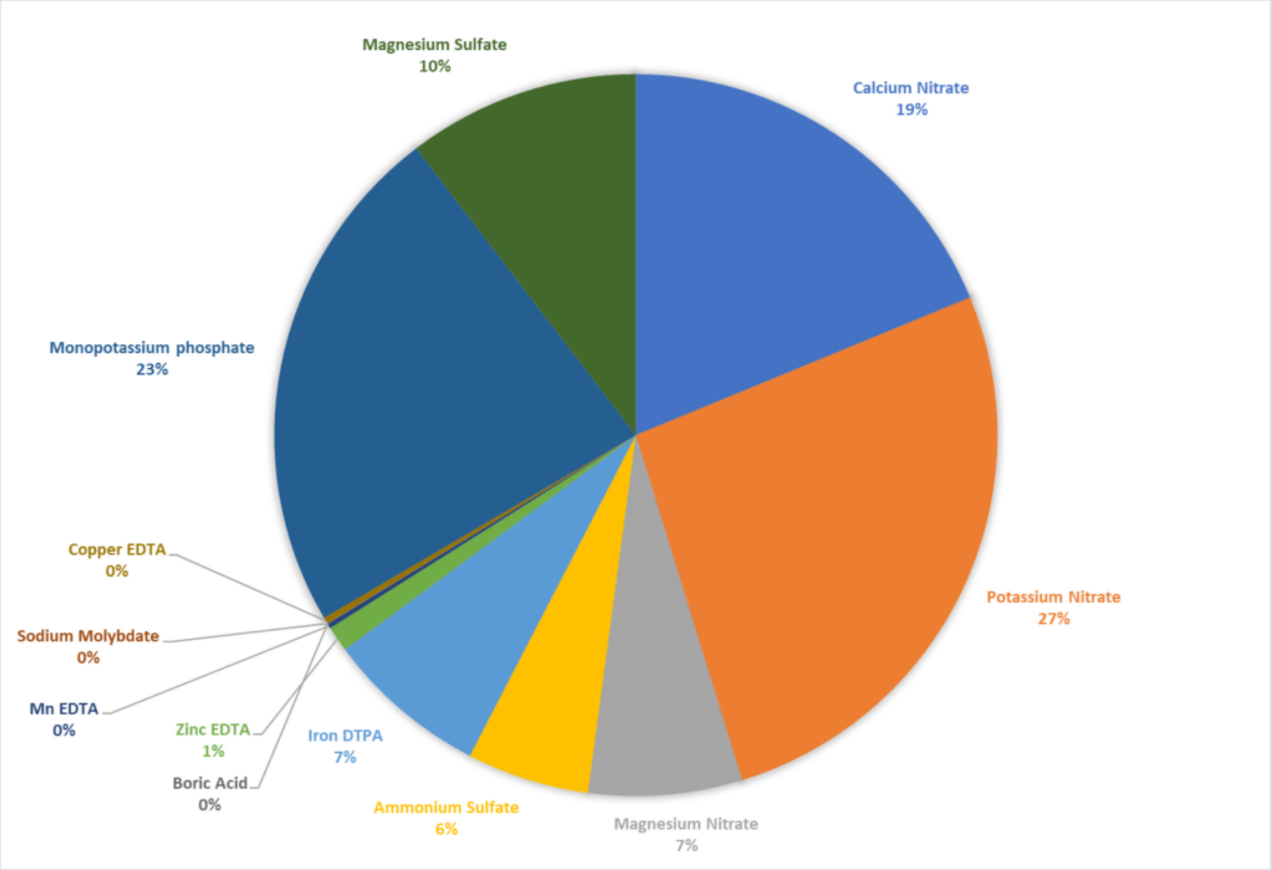
It is also interesting to consider the case of raw fertilizer inputs as this allows us to better think about formulations to reduce cost and also calculate whether making custom fertilizers is worth the expense. The table below shows you some commonly used bulk fertilizer inputs, their cost in USD and the cost per pound of each one of the products.



Chemical	Cost	Amount (lb)	Cost/lb
AgSil 16H	321.84	50.00	6.44
Ammonium Sulfate	45.98	50.00	0.92
Boric Acid	9.54	1.00	9.54
Calcium Nitrate	37.86	50.00	0.76
Copper EDTA	185.46	20.00	9.27
Iron DTPA	490.08	55.00	8.91
Magnesium Nitrate	69.27	50.00	1.39
Magnesium Sulfate	29.92	50.00	0.60
Mn EDTA	28.08	7.00	4.01
Monoammonium phosphate	75.13	20	3.76
Monopotassium phosphate	155.04	50.00	3.10
Phosphoric Acid (75%)	1575.00	86.90	18.12
Potassium Hydroxide	106.80	50.00	2.14
Potassium Nitrate	66.75	55.00	1.21
Potassium Sulfate	76.28	55.00	1.39
Sodium Molybdate	23.70	1.00	23.70
Sulfuric Acid (40%)	259.53	71.50	3.63
Zinc EDTA	384.09	55.00	6.98

Cost and cost per pound of each fertilizer input

Micronutrients are the most expensive per pound, but since they are used at very low amounts, their total cost contribution to fertilizer solutions is often less than 0.002 USD/gal (not counting the iron). The cost of the bulk fertilizers is much more important from a cost impact perspective. From these fertilizers, potassium inputs are often the most expensive. Both potassium nitrate, potassium sulfate and monopotassium phosphate are usually large contributors to the total price of a hydroponic formulation. Soluble silicon amendments, like AgSil16H, are also often large contributors to the overall price of these formulations. The above analysis also shows that Phosphoric acid is a very expensive option for pH adjustments in hydroponics. For this reason – and a few other reasons out of the scope of this post – sulfuric acid should almost always be used.



Cost contribution of bulk fertilizers to a custom hydroponic formulation.

The image above shows you the bulk contributions of all the raw inputs used in a sample custom formulation. The total cost of this formulation is around 0.016 USD/gal. If we supplemented Silicon from AgSil16H, the cost of this formulation would likely increase to close to 0.025-0.03g/gal depending on how much Si we would like to add. You can see here that the highest bulk costs are indeed the monopotassium phosphate and the potassium nitrate, it is unlikely that we would be able to diminish this cost contribution substantially, as this is the true bottom line of the fertilizer industry.

For most of my clients, formulation costs in real life will usually be between 0.01-0.03 USD/gal. The final cost will depend on which bulk discounts are available at scale, which plants the client is growing, what the cost of shipping the fertilizer is and which additional amendments beyond simple raw fertilization we choose to use. Sometimes, by using the nutrients already present in the water, substantial additional savings are possible with custom formulations.

Note that the above raw input analysis does not include the cost of labor to prepare the concentrated nutrients needed for injection. If a worker needs to spend a couple of hours per week mixing 25 gallons of each fertilizer then this, at 20 USD/hour, would likely increase the cost of the fertilizer by around 2-5%. Since workers can often mix batches of concentrated solutions that end up creating thousands of gallons of solution, the labor cost needed to mix fertilizers is often not meaningful relative to the overall cost of the inputs.

Balance between complexity and cost

From the above, it is clear that making your own fertilizer has the lowest cost, even *at a small scale*. However, it does add a substantial level of complexity to an operation and exposes the operation to a variety of potential mistakes dealing with preparation. A careful consideration of the advantages and disadvantages of mixing your fertilizer needs to be made. For large facilities, I believe this to be a no-brainer. At scale, it almost certainly makes sense to mix your own fertilizers.

However, it is true that at a medium scale, a grower might benefit from not doing their own mixing, as this simplifies their operation and allows them to focus on growing great plants while they grow. In this case, you can certainly – regardless of the plant you're growing – create a formulation based on a widely available agricultural industry blend with perhaps one or two raw inputs, to achieve a highly cost effective formulation.

Of course, there is also an additional cost to fertilizer formulation, which – per the prices charged by myself and other colleagues – might cost you from hundreds to thousands of dollars depending on complexity. If you do not want to incur this cost, then you should bear in mind you will pay a perpetually higher price in your fertilizers, to a company that has done the formulation work for you.

At a large scale, you definitely do not want to go with a formulation that reduces the yield or quality of your plant product, so – if you lack the experience to do these formulations yourself – always make sure to hire someone who knows what they are doing.

In the simplest case, a formulation schedule of an agricultural preblended product – using for example the Masterblend 5-11-26 mentioned above – adjusted to your situation might lower your costs by an order of magnitude from an expensive boutique shop at a minimal increase in complexity and low formulation costs. Of course you can always make your own Masterblend proxy as a first step when you move to fully custom formulations. If it is not possible to use these types of blends – due to for example your water composition – a fully custom formulation will be required.

There is no reason to pay even

higher prices

People in the traditional large scale hydroponic industry have been growing at very cost effective fertilizer prices for decades. If you are a small, medium or even large scale grower, there is no reason why your fertilizer costs should be astronomically high. There are no reasons to perpetually pay high margins to fertilizer companies and there is no reason why you shouldn’t take advantage of the easiest cost savings that can be achieved with products that are already available to the bulk agricultural industry. Now that the raw fertilizer input costs are even higher, it is more important than ever to go to lower cost methods to achieve your desired hydroponic formulations.

If you want to learn how to make your own fertilizers, then I advice you visit my youtube channel or read my blog articles on making your own fertilizers from raw inputs.

Are you using boutique fertilizers? Are you mixing your own? Please let us know about your experience in the comments below!

How to reuse your coco coir in soilless growing

Why reuse media

Buying new media and spending labor to mix, expand, and even amend it can be a costly process for growing facilities. Dumping media also involves going through a composting process, wasting nutrients that are already present in that media when it is thrown away. However, media in hydroponics serves a mostly structural role and there are no fundamental reasons why media like coco cannot be recycled and used in multiple crop cycles.

Coco coir commonly used as a substrate in soilless agriculture.

By reusing media, a grower can substantially reduce operational costs. This is because the media itself often contains an important amount of surplus nutrition and the roots and other organic components left behind by previous plants can also be used by new crops to sustain their growth. These added decomposing root structures also reduce channeling in the media and help improve its water retention as a function of time. After a media like coco is reused several times, the coco also degrades and becomes finer, further improving water retention.

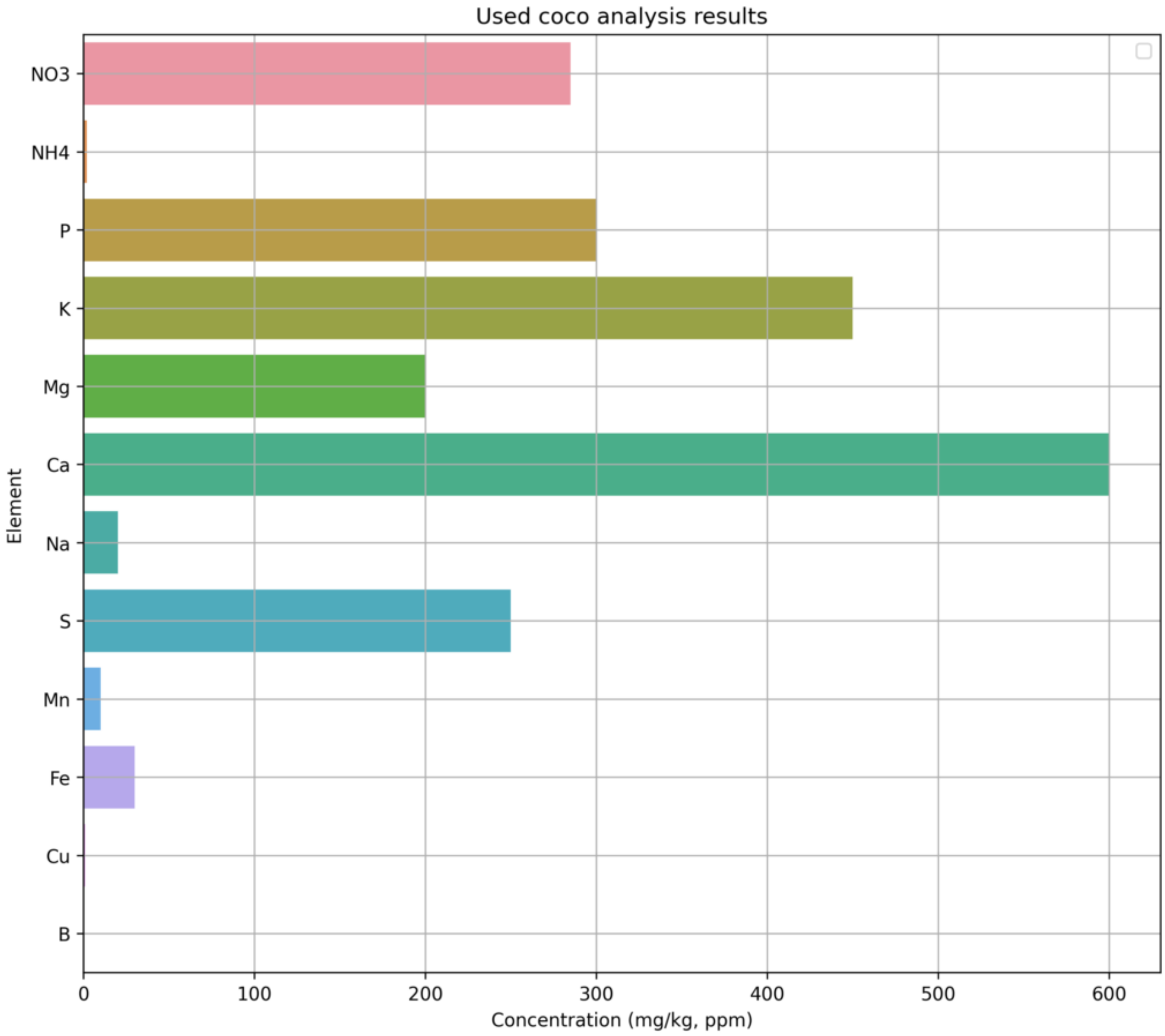
Why media is often not reused

Reusing media is not without peril. When media is pristine, it is more predictable. You know its basic composition and you can feed it the same set of nutrients and hope to obtain very similar results. Nonetheless, after media goes through a growing cycle, its chemical composition changes and the starting point becomes much more variable. This means that a grower needs to somehow adjust nutrition to the changes in composition, which can often make it difficult for the crop to achieve consistent results.

If a grower reuses media but tries to feed as if the media was new, then problems with overaccumulation of nutrients in the media will happen and it will be hard for the grower to obtain reliable results. Reusing media requires a different approach to crop nutrition which scares people away because it strays from what nutrient companies and normal growing practices require. However we will now learn how media is chemically affected by cultivation and how we can take steps to reduce these effects and then successfully reuse it.

Media composition after a normal crop

In traditional coco growing, fertilizer regimes will tend to add a lot of nutrients to the coco through the growing cycle. From these nutrients, sulfates, phosphates, calcium and magnesium will tend to aggressively accumulate in the media while nutrients that are more soluble like nitrate and potassium will tend to accumulate to a lesser extent or be easier to remove.



Analysis of used coco from a tomato crop. This analysis uses a DTAP + ammonium acetate process to extract all nutrients from the media. This media had a runoff pH of 6 with an EC of 3.0 mS/cm.

The above image shows you the analysis results of a coco sample that was used to grow a tomato crop. In this analysis, the media is extracted exhaustively using a chelating agent, to ensure that we can get a good idea of all the cations that are present in the media. The chelating agent overcomes the cation exchange capacity of the media, forcing all the cations out – fundamentally exchanging them for sodium or ammonium – and showing you the limits of what could be extracted from the media by the plant.

In this case, the amount of Ca is so high, that it can fundamentally provide most of the Ca required by a plant through its next growing period. Since most of this Ca is going to be present as calcium sulfate and phosphate, it will only be removed quite slowly from the root zone by leachate. The amount of potassium is also quite high, but this potassium is going to go out of the media quite easily and is only likely to last for a short period of time.

In addition to the above mineral content, coco that is reused will often contain a lot of plant material, roots that remained from the previous crop, so the subsequent reuse of the media needs to incorporate adequate enzymatic treatments to help breakdown these organics and ensure that pathogens are not going to be able to use these sources of carbon as an anchor point to attack our plants.

Steps before the crop ends

Because of the above, one of the first steps we need to carry out if we want to reuse media is to ensure that the media is flushed during the last week of crop usage with plain water, such that we can get most of the highly soluble nutrients out of the media so that we don’t need to deal with those nutrients in our calculations. This will remove most of the nitrogen and potassium from the above analysis, giving us media that is easier to use in our next crop.

In addition to this, we will also be preparing our media for the digestion of the root material. Before the last week of cultivation, we will add pondzyme to our plain water flushing at a rate of 0.1g/gal, such that we can get a good amount of enzymes into our media. We should also add some beneficial microbes, like these probiotics, at 0.25g/gal, so that we can get some microbial life into the media that will help us decompose the roots after the plants that are currently in the media will be removed.

How to manage the new crop

Once the crop ends, we will remove the main root ball from the media. There is no need to make an effort to remove all plant material as this would add a lot of labor costs to media reuse. The media should then be allowed to dry, such that the roots that are left behind can then be easily broken up before new plants are placed in the media. Machines to breakup any roots are ideal, although this can also be done manually and easily once all the root material in the media is dead and the roots lose their capacity to hold their structure together.

Once we have dry coco with the root structures broken up, we can then fill up new bags to reuse this media for our next crop. After doing a lot of media analysis and working with several people reusing media, I have found this method works well. If we performed the flushing steps as instructed before, then we can use the media runoff EC as a way to evaluate the type of nutrition needed.

While the runoff EC remains above *1.5mS/cm*, we feed a solution containing only potassium nitrate and micronutrients (no phosphorus, sulfates, calcium or magnesium) at 2g/gal of KNO_3 + micros. After the runoff EC drops below 1.5mS/cm we return to feeding our normal regime. The idea here is that while the media is above 1.5mS/cm the plant can take all the nutrients it needs from the media, but once the media EC drops below 1.5mS/cm, the media is deprived from these nutrients and we need to provide them again for the plant.

Bear in mind that while the nitrogen content of the above feed seems low (just 73 ppm of N from NO_3) there is additional nitrogen that is coming from the decomposition of the organic materials left in the media, which can supplement the nitrogen needs of the plants. Despite the flushing on the last week, there is always some nitrate left from the previous crop. I have found that this is enough to support the plant until the runoff drops below our 1.5mS/cm threshold. After this point, the plant can be grown with its normal nutrition.

Simple is better

Although you would ideally want to find exactly which nutrients are missing or present after each batch of media and adjust your nutrition such that you can get your plants the ideal nutrient composition every time, this is not cost effective or required in practice to obtain healthy plant growth. A media like coco possesses a good degree of nutrient buffering capacity (due to it’s high cation exchange capacity and how much nutrition is accumulated after a crop cycle), so it can provide the plants the nutrition of certain nutrients that they need as long as the nutrients that are most easily leached (K and N) are provided to some degree.

The above strategy is simple and can achieve good results for most large crops that are grown using ample nutrients within their normal nutrient formulations. It is true that this might not work for absolutely all cases (or might need some adjustments depending on media volumes) but I’ve found out it is a great strategy that avoids high analysis costs and the need to create very custom nutrient solutions.

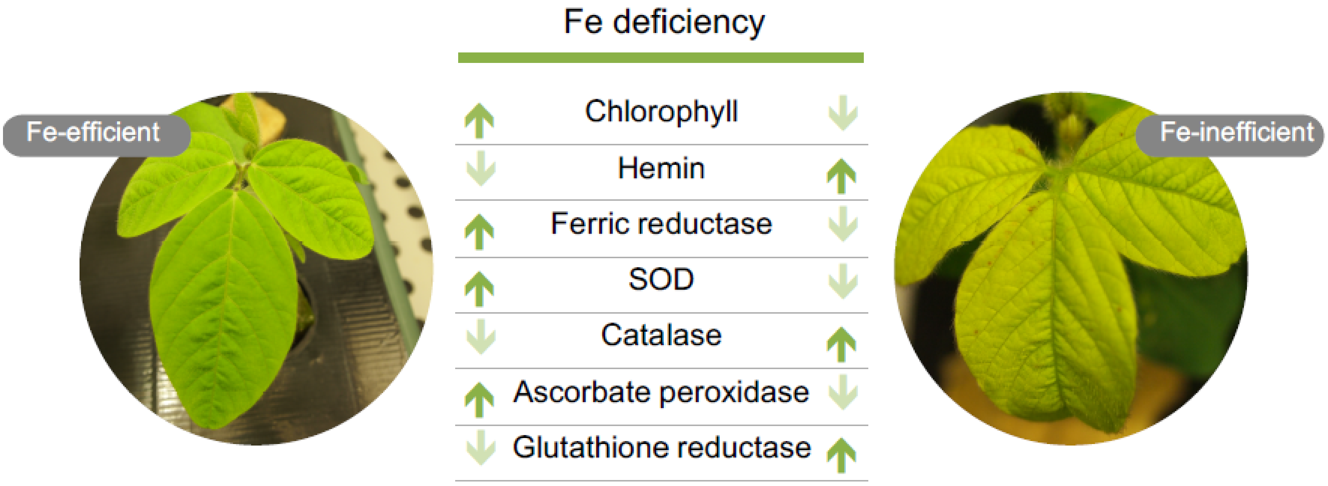
Do you reuse your coco? Let us know which strategy you use and what you think about my strategy!

Are Iron chelates of

humic/fulvic acids better or worse than synthetics?

Why Fe nutrition is problematic

Plants need substantial amounts of iron to thrive. However, iron is a finicky element, and will react with many substances to form solids that are unavailable for plant uptake. This is a specially common process under high pH, where iron can form insoluble carbonates, hydroxides, oxides, phosphates and even silicates. For this reason, plant scientists have – for the better part of the last 100 years – looked for ways to make Fe more available to plants, while preventing the need for strategies that aim to lower the pH of the soil, which can be very costly when large amounts of soil need to be amended.



The image above is taken from this paper on Fe deficiencies.

In hydroponics, the situation is not much better. While we can add as much Fe as we want to the hydroponic solution, the above processes still happen and the use of simple Fe salts (such as iron nitrate or iron sulfate) can lead to Fe deficiencies as the iron falls out of solution. This can happen quickly in root zones where plants aggressively increase the pH of solutions through heavy nitrate uptake.

For a better understanding of the basics of soil interactions with microbes, plants and the overall Fe cycle, I suggest reading this review (6).

Synthetic chelates to the rescue

The above problems were alleviated by the introduction of synthetic iron chelates in the mid 20th century. The chelating agents are organic moieties that can wrap around the naked metal ions, binding to their coordination sites. This kills their reactivity and ensures that they do not react with any of the substances that would cause them to become unavailable to plants. Plants can directly uptake the chelates, take the iron and push the chelate back into solution, or they can destroy the chelate and use its carbon within their metabolism.

Chelates can bind Fe very strongly though, and this is not desirable for some plants that do not have the enzymatic machinery required to open these “molecular cages”. Studies with monocots (1) – which are grasses – have often found that these plants respond poorly to Fe supplementation with molecules like Fe(EDDHA), a very powerful chelate. So powerful in fact, that not even the plants can get the Fe out. For these plants, weaker chelates often offer better results, even at higher pH values.

Another problem is that many of the synthetic chelates are not very good at high pH values. When the pH reaches values higher than 7.5, chelates like EDTA and DTPA can have problems competing with the much more strongly insoluble salts that form at these pH values. The chelated forms are always in equilibrium with the non-chelated forms and the minuscule amount of the non-chelated form drops so quickly out of solution that the entire chelate population can be depleted quite quickly. (2)

Chelates that respond well to high pH values, like EDDHA, are often much more expensive. In the case of EDDHA, the presence of a lot of isomers of the EDDHA molecule that are weaker chelates, also creates problems with quality control and with the overall strength of each particular EDDHA source. The EDDHA is only as good as its purification process, which makes good sources even more expensive (3, 4).

An additional concern is the oxidation state of the Fe. While Fe chelates are usually prepared using ferrous iron (Fe^{2+}), these iron chelates are quickly oxidized in solution to their ferric iron (Fe^{3+}) counterparts, especially when the solution is aerated to maintain high levels of oxygen. Since Fe^{3+} is both more tightly bound to chelates and more reactive when free – so more toxic when taken up without reduction – plants can have an even harder time mining Fe^{3+} out of chelates (5, 7).

Then there are naturally occurring chelates

There are many organic molecules that can form bonds with the coordination sites of Fe ions. Some of the reviews cited before go into some depth on the different groups of organic molecules that are excreted by both plants and microorganisms as a repose to Fe deficiency that can lead to improved Fe transport into plants. Some of these compounds are also reductive in nature, such that they can not only transport the Fe, but reduce it to its ferrous form such that it can be handled more easily by plants.

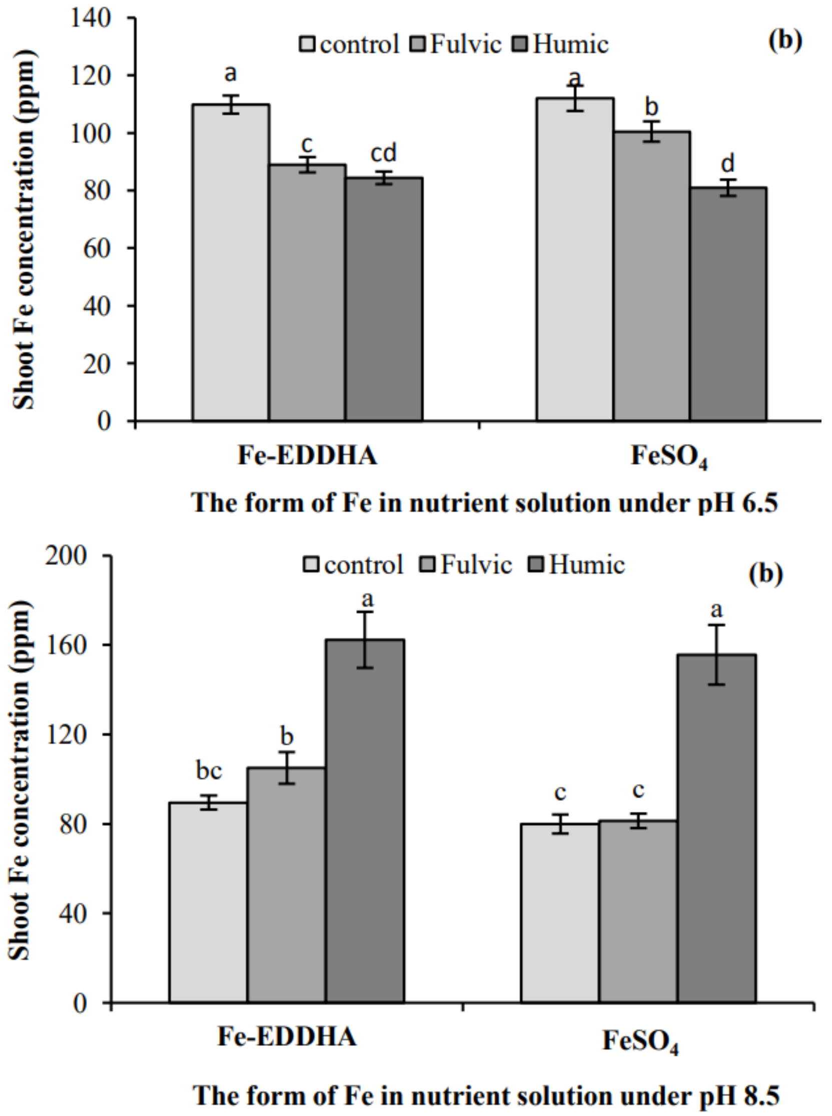
Among the organic compounds that can be used for Fe chelation, humic and fulvic acids have attracted attention, as they can be obtained at significantly low costs and are approved for organic usage under several regulations. You can read more about these substances in some of my previous posts about them

(8, 9). In particular, humic acids are more abundant and are formed by larger and more complex molecules compared to fulvic acids.

The ability of these substances to chelate Fe is much weaker than that of synthetic chelates. The pKb shows us the strength of the binding equilibrium of the chelate with the free metal ion (you can see the values for many metals and chelating agents here). The value for EDTA is 21.5 while that of most humic and fulvic acids is in the 4-6 range (10). This is a logarithmic scale, so the difference in binding strength is enormous. *To put things into perspective, this difference in binding strength is of the same magnitude as the difference between the mass of a grain of sand and a cruise ship.*

Comparing synthetic and fulvic/humic acid chelates

There aren’t many studies comparing synthetic and humic/fulvic acid chelates. One of the most explicit ones (11) compares solutions of Fe sulfate (which we can consider unchelated) and Fe(EDDHA) after additions of fulvic or humic acids in the growth of Pistachio plants. At pH values close to those generally used in hydroponics (6.5) there is hardly any difference between any of the treatments while at higher pH values we have substantially better uptake of Fe in both the EDDHA and unchelated iron treatments when supplemented with either fulvic acid or humic acid.



Images at pH 8.5 of Fe in shoots from the Pistachio study (11)

The idea of using humic acids as a compliment of traditional chelate based fertilization to alleviate high fertilization costs has also been studied in citrus (13). This study confirms some of the findings of the previous one, where additions of humic acids to solutions already containing Fe(EDDHA) provided a more beneficial role than simply the use of the pure humic acid substances or pure Fe(EDDHA) fertilization. Another study on citrus (14) showed that humic acid applications could in fact provide Fe supplementation in calcareous soils (these are soils with high pH values). This shows how humic acid fertilization can rival Fe-EDDHA fertilization.

In another study of leonardite iron humate sources and EDDHA in soybean roots (12) it is apparent that accumulation of Fe in shoots and roots is much worse under the humic acid treatments. In the conclusions of the paper, it is highlighted that the high molecular mass of the leonardite constituents might block the roots of the soybean plants, therefore making it difficult for the plant to transport Fe. However, this study does show that the accumulation of these humic acids in the root zone does promote a decrease in the expression of genes that create Fe transporters and Fe reducing enzymes, pointing that the plant is indeed under less Fe deficiency stress. Another important point is that cycling the humic acid application promotes the absorption of accumulated humic acids, cleaning the roots and allowing for better transport of the Fe in the roots.

In a separate study with humic acid + $FeSO_4$ applications compared to Fe(EDDHA) in sweet cherry (13) it was found that the humic acid, when supplemented with unchelated iron, increased Fe tissue as much as the Fe(EDDHA) applications. This was consistent across two separate years, with the second year showing a statistically significant increase of the humic acid treatment over the Fe(EDDHA).

How does this work

An interesting point – as I mentioned before – is that humic/fulvic acids are *incredibly weak* chelating agents. This means that they should release their Fe to the bulk of the solution, which should lead to Fe depletion and deficiencies, as the Fe precipitating mechanisms are thermodynamically much more stable. However this is not what we consistently observe in the studies of Fe nutrition that try to use humic/fulvic acids, either with or without the presence of additional synthetic chelates.

The reason seems to be related with the kinetics of Fe release from these substances. While the stability constants of the chelates are weak – therefore they will release and precipitate in the long term – the bulkiness of the ligands and the complex structures surrounding the metals, makes it hard for the metal to actually escape from the chelate structures around it. However, the fact that the bonding is thermodynamically weak, ensures that the metal can be easily transported once it leaves the organic chelate structure.

Another point is that humic/fulvic substances are reductive in nature, which means that they will protect Fe^{2+} from oxidation by either microbes or oxygen dissolved in solution. They are also sometimes able to reduce Fe^{3+} present in solution back to Fe^{2+}, which can help with the uptake of this Fe by the plant’s root system.

The nature of the above structures and their reductive power depends fundamentally on the actual humic/fulvic acid used, so – as with all cases pertaining to fulvic/humic substances – the source you use will play a big role in determining the final outcome you get.

What chelates are the best?

Current research shows that Fe(EDDHA) and similar chelates, despite their high stability constants, are not perfect. While they can provide ample iron for dicots and can cure Fe deficiencies in the large majority of cases for these plants, these strong chelates are often very expensive and their use as sole Fe sources might be impractical for many cases in traditional agriculture and hydroponics/soilless growing.

The use of humic/fulvic acids complimented with either unchelated Fe or with some lower proportion of stronger iron chelates, seems to be a better overall choice in terms of both plant uptake and economic expense. As shown by several studies mentioned in this post, the effect of humic/fulvic acids and synthetic chelates might actually be synergistic, with both providing different advantages that can be complimentary in hydroponic solutions. These humic/fulvic acid solutions might also be much more favorable for monocot species, where the use of highly stable Fe(EDDHA) chelating agents does not cure deficiency symptoms.

The take away here is that chemical chelate strength is not the only thing to consider. The kinetics of the chelate dissociations, as well as how the chelates interact with the root system, for example how the plant can actually take the Fe outside of the chelating system, are all very important to establish whether the Fe is effectively absorbed and transported by the plants.

Please note that the topic of Fe nutrition is extremely extensive and while the above is intended to be a short introduction to the topic of humic/fulvic acids and how they compare to synthetic chelates, it is by no means an exhaustive literature review.

Are you using fulvic or humic acids for Fe nutrition? Let us know what your experience is in the comments below.

A guide to different pH up options in hydroponics

When is pH up needed?

The control of pH in hydroponics is critical. Most commonly, we need to decrease the pH of our solutions as most nutrients will initially be at a higher than desired pH. This is especially true when tap water or silicates are used, as both of these inputs will increase the overall pH of hydroponic nutrients after they are prepared. In recirculating systems, pH will also tend to drift up due to the charge imbalance created by the high active uptake of nitrate ions carried out by most plant species. For a discussion on pH down options, please read my previous post on this topic.

However, there are certain circumstances where the pH of hydroponic solutions needs to be increased. This can happen when tap water or silicates are not used or when plants decrease pH due to an aggressive uptake of some cations. Plants like tomatoes can do this when grown in solutions with high potassium contributions, as they will actively uptake these nutrients to the point of changing pH balance. Excess ammonium can be another common cause for pH decreases in hydroponic solutions that require the use of pH up solutions.

Potassium hydroxide pellets, the most powerful pH up option available to growers

With this in mind, let’s discuss the pH up options that are available in hydroponics. I only considered substances that are soluble enough to create concentrated solutions, such that they can be used with injector systems.

pH up options

Sodium or potassium hydroxide (NaOH, KOH)

These are the strongest. They are low cost, can be used to prepare highly concentrated solutions and will increase the pH most effectively. They are however unstable as a function of time because they react with carbon dioxide from the air to form sodium or potassium carbonates. This means that their concentrated solutions need to be kept in airtight containers and that their basic power will decrease with time if this is not the case. Additionally, these hydroxides are extremely corrosive and their powder is an important health hazard. Dissolving them in water also generates very large amounts of heat – sometimes even boiling the water – which makes their usage more dangerous. Although desirable when basic power is the most important short term concern, I recommend to avoid them giving their PPE requirements and the lack of long term stability.

When these hydroxides are used, potassium hydroxide is the recommended form, as potassium hydroxide is both more basic and a plant nutrient, while excess sodium can cause problems with plant development. However, sodium hydroxide might be more desirable if it can be obtained at a particularly low price and small additions of sodium are not a concern.

Potassium silicate

This is a soluble form of silicon that is stable at high pH values. While solutions of potassium silicate by itself can be prepared and used as a pH up option, it is usually stabilized with a small addition of potassium hydroxide to take the pH of solutions to the 11-12 range. Potassium silicate contributes both potassium and silicon to hydroponic solutions – both important nutrients – and its use can be more beneficial than the use of pure potassium hydroxide. While silicates are less basic and more mass is required for the same pH buffering effect, the preparation and handling can often be much simpler than those of potassium hydroxide.

Note that potassium silicate solutions are also unstable when left in open air, as they will also react with atmospheric carbon dioxide to generate potassium carbonate. It is also worth noting that not all potassium silicates are the same, when looking for a highly soluble potassium silicate for hydroponics, make sure you get potassium silicates that have higher K/Si ratios. Usually ratios of at least 1.05 are required (make sure you convert both K and Si to their elemental forms, as most of these products report K as K_2O and Si as SiO_2).

Potassium carbonate (K_2CO_3)

This basic salt is stable in air, has less demanding PPE requirements and can also be used to prepare concentrated solutions (more than 1g of potassium carbonate can be dissolved per mL of water). Because of its lower basicity compared to potassium hydroxide, more of it also needs to be used to increase the pH of a hydroponic solution. However, solutions of it are stable, so there is no concern for their stability or changes to its basic power.

Another advantage given by potassium carbonate is that – contrary to the previous two examples – it does increase the buffering capacity of the solution against pH increases, due to the addition of carbonate to the solution. As carbon dioxide is lost to the air at the pH used in hydroponics, the pH of the solutions tends to drift up, this means that the carbonate addition makes the pH more stable in solutions where the pH is being constantly pushed down. This is all part of the carbonic acid/bicarbonate equilibrium, which also helps chemically buffer the solutions at the pH used in hydroponics.

Overall potassium carbonate is one of my favorite choices when there is a downward drift of pH in recirculating solutions.

Potassium phosphate (K_3PO_4)

Another weak base, potassium phosphate, can be used to prepare concentrated solutions and increase the pH in hydroponic solutions. While its solubility and basicity are lower than that of potassium carbonate, it does provide additional phosphorus that can buffer the pH of the solution. This happens because mono and dibasic phosphate ions are anions that be taken up by plants, therefore decreasing the pH. While phosphates can help chemically buffer the hydroponic solution against pH increases, for decreases the phosphate buffer is ineffective as the pKa of the relevant equilibrium is 7.2.

An issue with potassium phosphate is that it provides large contributions of K to solution. These potassium additions can be quite counter productive if the cause of the pH drift towards the downside is related to potassium uptake.

Potassium Citrate/Lactate/Acetate

Basic organic salts of potassium can also be used to increase the pH. These are all much weaker than even the carbonate and phosphate bases mentioned above and relatively large additions are required for even a moderate immediate effect in pH. However, since these anions are actively taken up by microbes, the microbial metabolism of these ions will create a longer term effect on pH. A moderate addition of potassium citrate can only cause a small increase of pH in the short term, with a larger increase happening during the following 24 hours.

A disadvantage is that these anions can also lead to explosions in bad microbe populations if the environment does not have an adequate microbial population. When these salts are used, adequate microbial inoculations need to be carried out to ensure that the microbes that will proliferate will not be pathogenic in nature.

Protein Hydrolysates

While hydrolysates themselves can have an acidic pH when put in solution, their microbial metabolism aggressively increases the pH of solutions in the medium term. This means that these hydrolysates should not be used for immediate pH adjusting, as they will tend to decrease pH further in the very short term, but they can be used as a more long term management option.

As with the above organic salts, their use also requires the presence of adequate microbial life. If you neglect to properly inoculate the media before their addition, then pathogens can also make use of these amino acids to proliferate.

Combinations are also possible

As with the case of pH down options, some of the best solutions for a problem come when several of the above solutions are combined. For example the use of potassium rich pH up solutions in microbe containing soilless media can often cause pH drift issues related with potassium to worsen. For this reason, it can be desirable in these cases to prepare pH up solutions that include protein. This means that you reduce the pH fast but then you have a residual effect from protein metabolism that helps you fight the pH increase as a function of time.

However not all pH up drifts are caused by potassium, as in the case of plants where pH up drift happens due to low nitrate uptake (for example some flowering plants that stop producing a lot of additional leaves during their flowering stage). In these cases potassium based pH up solutions cause no additional issues and combinations of potassium carbonate and potassium phosphate might be best.

Choose according to your goals

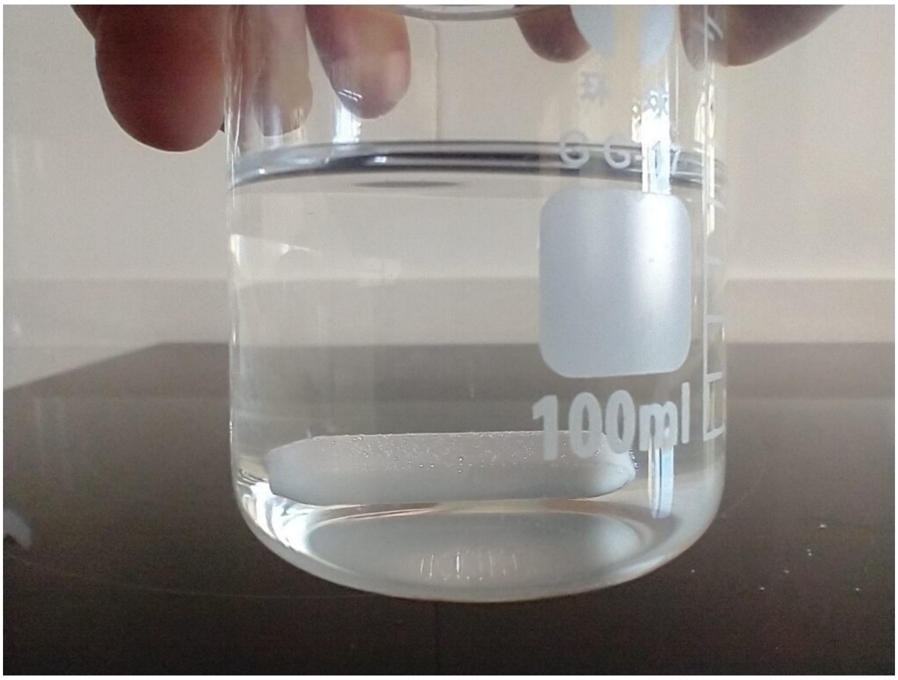
As in most cases, the best solution will depend on your circumstances. Think about whether you're just adjusting the pH of your initial solutions or whether you need to compensate for a constant drift, whether microbial life is present and whether you're concerned with the accumulation of any substances in a recirculating solution. Once you consider these factors and review the above solutions, you should be able to find the pH up solution that is better suited to your particular needs.

Are you using a pH up? Let us know why and which one you're using in the comments below!

How to make a stabilized ortho-silicic acid solution with only 3 inputs

In a previous post, which you can read here, I gave a procedure for the preparation of a stabilized mono-silicic acid using from potassium silicate. The procedure called for the usage of several stabilizing agents, including carnitine and propylene glycol, with phosphoric acid being used as the acidifying agent.

After trying this synthesis myself and talking with other people who tried this process, it seemed clear that the success rate was low and that the process was just too complicated and imprecise for most people to carry out (especially for the patience needed for the addition of the solid potassium silicate). There is a detailed discussion about this procedure, as well as mono-silicic acid synthesis in this forum thread.



Stabilized mono-silicic acid solution created using the procedure below. Note that mono-silicic acid and ortho-silicic acid are the exact same thing, they are two names for the same molecule (H_4SiO_4). Another molecule with the same nomenclature is ortho-phosphoric acid (H_3PO_4), which is also called mono-phosphoric acid.

Given these issues, I decided to look for a potentially easier synthesis starting from cheaper, more readily available materials, avoiding the use of Propylene Glycol (which concerned some people) and trying to simplify the steps involved.

The procedure I came up with simplifies the process by relying on the interaction of silicic acid with sorbitol as a stabilizing agent. This stabilization process is well documented in the literature (see here) and is caused by the formation of highly stable polyolate complexes between mono-silicic acid and molecules like sorbitol. These complexes form because molecules like sorbitol have adjacent hydroxy groups in what we call a *threo* configuration. These do not exist in sugars like glucose or sucrose, reason why these do not work for this process.

The raw inputs you will need are as followed

1. A potassium silicate with a high K/Si ratio, such as AgSil 16H. You can also use a liquid potassium silicate, such as Grotek Pro-silicate.
2. Sulfuric Acid (>90%)
3. Sorbitol
4. Distilled water.

If using AgSil16H follow this process first. In a 1000mL beaker, add 70g of AgSil16H and 450mL of distilled water. Stir – ideally with magnetic stirring – until the silicate has all dissolved. This will be the silicate solution.

This is now the procedure to prepare the stabilized ortho-silicic acid solution (700mL):

1. In a 1000mL beaker, add 500mL of distilled water and a magnetic stirrer.
2. Weigh 200g of Sorbitol and add them to the water.
3. Start the magnetic stirring.
4. After the sorbitol has completely dissolved, during a period of 30 seconds add 100mL of the silicate solution (either as prepared above or a commercial silicate equivalent to the Grotek suggestions above (around 7.5% Si as SiO_2)).
5. Stir the silicate and sorbitol solution for 10 minutes.
6. Add 10mL of >90% sulfuric acid and stir for 5 minutes. The pH should now be lower than 2.
7. The solution can now be stored.

The above process creates a stable mono-silicic acid solution that has an Si concentration of around 1% of Si as SiO_2 and around 0.6% K as K_2O. **Used at 8mL gal it should provide around 20ppm of Si As SiO_2 and 10 ppm of K.**

A previous version of this procedure used 50mL of 80-85%

phosphoric acid. However, phosphoric acid seems to generate solutions that are unstable after 1-2 weeks of preparation. Solutions prepared per the above process have been confirmed to be stable for at least 1 month.

Did you try it? How were your results? Let us know in the comments below!

A one-part hydroponic nutrient formulation for very hard water

What is water hardness?

There are many parameters that determine the quality of a water source. Water that has a composition closer to distilled water is considered of a higher quality, while water with many dissolved solids or high turbidity is considered low quality. Calcium carbonate, magnesium carbonate, calcium sulfate and calcium silicate are some of the most common minerals that get dissolved into water as it runs through river beds and underground aquifers. The carbonates and silicates will make water more basic, will increase the water's buffering capacity and will also increase the amount of magnesium and calcium present in the water.

Water hardness is determined experimentally by measuring the amount of Calcium and Magnesium in solution using a colorimetric titration with EDTA. Although both Calcium hardness (specific amount of Ca) and Magnesium hardness (specific amount of Mg) are measured, total water hardness (the sum of both) is the usually reported value. The result is often expressed as mg/L of $CaCO_3$, telling us how much $CaCO_3$ we would require to get a solution that gave the same result in the EDTA titration.

The Calcium and Magnesium present in water sources with high hardness is fully available to plants – once the pH is reduced to the pH used in hydroponics – and it is therefore critical to take these into account when formulating nutrients using these water sources. *It is a common myth that these Ca and Mg are unavailable, this is not true.*

What about alkalinity?

Water alkalinity tells us the equivalent amount of calcium carbonate we would need to add to distilled water, to get water that has the same pH and buffering capacity. An alkalinity value of 100 mg/L of $CaCO_3$ does not mean that the water has this amount of carbonate, but it means that the water behaves with some of the chemical properties of a solution containing 100mg/L of $CaCO_3$. In this particular case, it means that the water requires the same amount of acid to be titrated as a solution that has 100mg/L of $CaCO_3$.

Water sources with high hardness will also tend to have high alkalinity as the main salts that dissolve in the water are magnesium and calcium carbonates. Since these carbonates need to be neutralized to create a hydroponic solution suitable to plants, the anion contribution of the acid that we will use to perform the neutralization needs to be accounted for by the nutrient formulation.

An example using Valencia, Spain

Valencia, in the Mediterranean Spanish coast (my current home), has particularly bad water. Its water has both high alkalinity and high hardness, complicating its use in hydroponics. You can see some of the characteristics of the water below (taken from this analysis):

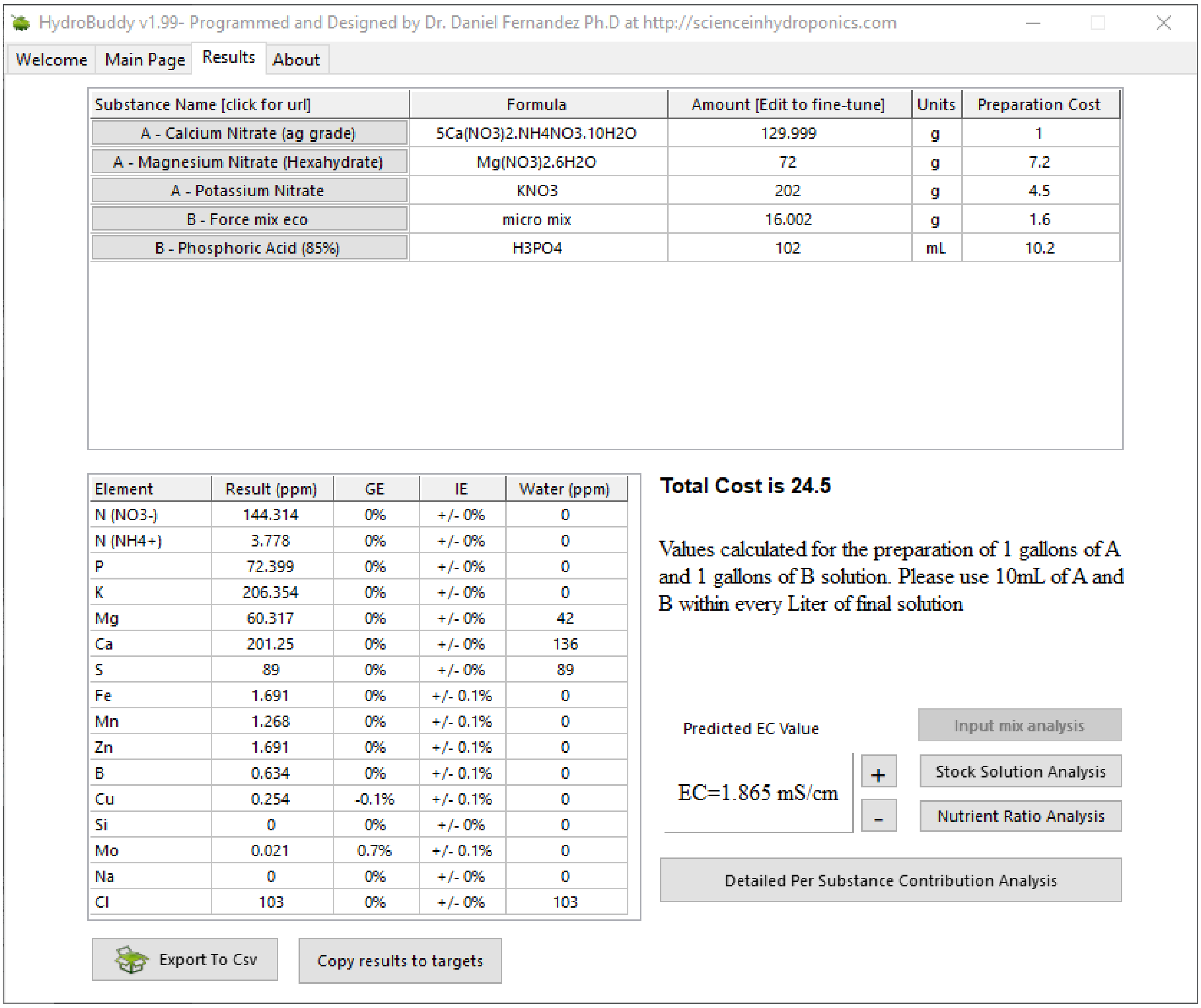
Name	Value	Unit
Calcium	136	ppm
Magnesium	42	ppm
Chloride	103	ppm
Sulfur	89	ppm
pH	7.6	
Alkalinity	240	mg/L of $CaCO_3$

Typical water quality values for water in Valencia, Spain.

Hard water creates several problems. Since Calcium nitrate is one of the most common sources of Nitrogen used in hydroponics, how can we avoid using Ca nitrate? Since we have more than enough. Also, how can we neutralize the input water so that we can make effective use of all the nutrients in it without overly increasing any nutrient, like P, N or S, by using too much of some mineral acids?

Creating a one-part solution for very hard water

HydroBuddy allows us to input the characteristics of the input water into the program so that we can work around them while designing nutrient solutions. To get around the above mentioned problems – but still ensure I could easily buy all the required chemicals – I decided to use a list of commonly available fertilizers. I used Calcium Nitrate, Magnesium Nitrate, Potassium Nitrate, Phosphoric acid (85%) and a micro nutrient mix called Force Mix Eco (to simplify the mixing process). This micronutrient mix is only available to people in the EU.



Substance Name [click for url]	Formula	Amount [Edit to fine-tune]	Units	Preparation Cost
A - Calcium Nitrate (ag grade)	5Ca(NO3)2.NH4NO3.10H2O	129.999	g	1
A - Magnesium Nitrate (Hexahydrate)	Mg(NO3)2.6H2O	72	g	7.2
A - Potassium Nitrate	KNO3	202	g	4.5
B - Force mix eco	micro mix	16.002	g	1.6
B - Phosphoric Acid (85%)	H3PO4	102	mL	10.2

Element	Result (ppm)	GE	IE	Water (ppm)
N (NO3-)	144.314	0%	+/- 0%	0
N (NH4+)	3.778	0%	+/- 0%	0
P	72.399	0%	+/- 0%	0
K	206.354	0%	+/- 0%	0
Mg	60.317	0%	+/- 0%	42
Ca	201.25	0%	+/- 0%	136
S	89	0%	+/- 0%	89
Fe	1.691	0%	+/- 0.1%	0
Mn	1.268	0%	+/- 0.1%	0
Zn	1.691	0%	+/- 0.1%	0
B	0.634	0%	+/- 0.1%	0
Cu	0.254	-0.1%	+/- 0.1%	0
Si	0	0%	+/- 0%	0
Mo	0.021	0.7%	+/- 0.1%	0
Na	0	0%	+/- 0%	0
Cl	103	0%	+/- 0%	103

Total Cost is 24.5

Values calculated for the preparation of 1 gallons of A and 1 gallons of B solution. Please use 10mL of A and B within every Liter of final solution

Predicted EC Value

EC=1.865 mS/cm

HydroBuddy results to create 1 gallon of 1:100 nutrient solution for Valencia's very hard water.

Note that we use absolutely no phosphates or sulfates, since the solution already contains more than enough sulfur (89 ppm) and we need to add all the Phosphorus as phosphoric acid to be able to lower the alkalinity. I determined the amount of P to add by setting P to zero, then using the "Adjust Alkalinity" to remove half of the alkalinity of the water using phosphoric acid. This is more than enough P to be sufficient for higher plants. The above nutrient ratios should be adequate for the growth of a large variety of plants, although they are a compromise and not ideal for any particular type of plant.

Since we are adding no sulfates and the pH of the solution is going to be very low (because of the phosphoric acid), we can add all of these chemicals to the same solution (no need to *make A and B solutions). The values in the image above are for the preparation of 1 gallon of concentrated solution. This solution is then added to the water at 38mL/gal of tap water to create the final hydroponic solution.*

Does it work?

I have experimentally prepared the above concentrated solution – which yields a completely transparent solution – and have created hydroponic solutions I am now using to feed my home garden plants. After adding to my tap water – initial pH of 7.6 – I end up with a solution at a pH of 5.6-5.8 with around 1.5-1.8mS/cm of electrical conductivity. The plants I'm currently growing – basil, rosemary, chives, mint, malabar spinach and spear mint – all seem to thrive with the above solution. I am yet to try it on any fruiting crops, that might be something to try next year!

Are you growing using hard water, have you prepared a similar one-part for your hard-water needs? Let us know what you think in the comments below!

New tissue analysis feature in HydroBuddy v1.99

Tissue Analysis

To grow great plants, we need to grow plants that have a healthy mineral composition. Although there are no theoretically established values for what the mineral composition of a plant should look like, we have grown healthy plants and have established, through analysis of their tissue, what this mineral composition should empirically be. By sampling the leaf tissue from your plants and sending it to a lab for analysis, you can know what the composition of your tissue is and how it compares to healthy plants grown by others.

The question is, can we create a nutrient formulation just from the tissue composition we want to get?

Nutrient solution targets from tissue analysis

Turns out, you can figure out the elemental concentrations that are required in solution to get to certain concentrations in tissue. My colleague and friend – Bruce Bugbee – proposed in this paper about nutrient management in 2004 how this could be done. To achieve this, we make the assumption that all elements taken up by the plant will be deposited as minerals upon transpiration – because minerals cannot leave the plant as gases – so knowing the amount of water that will transpired per amount of tissue grown, we can figure out how much of that element needs to be in the water.

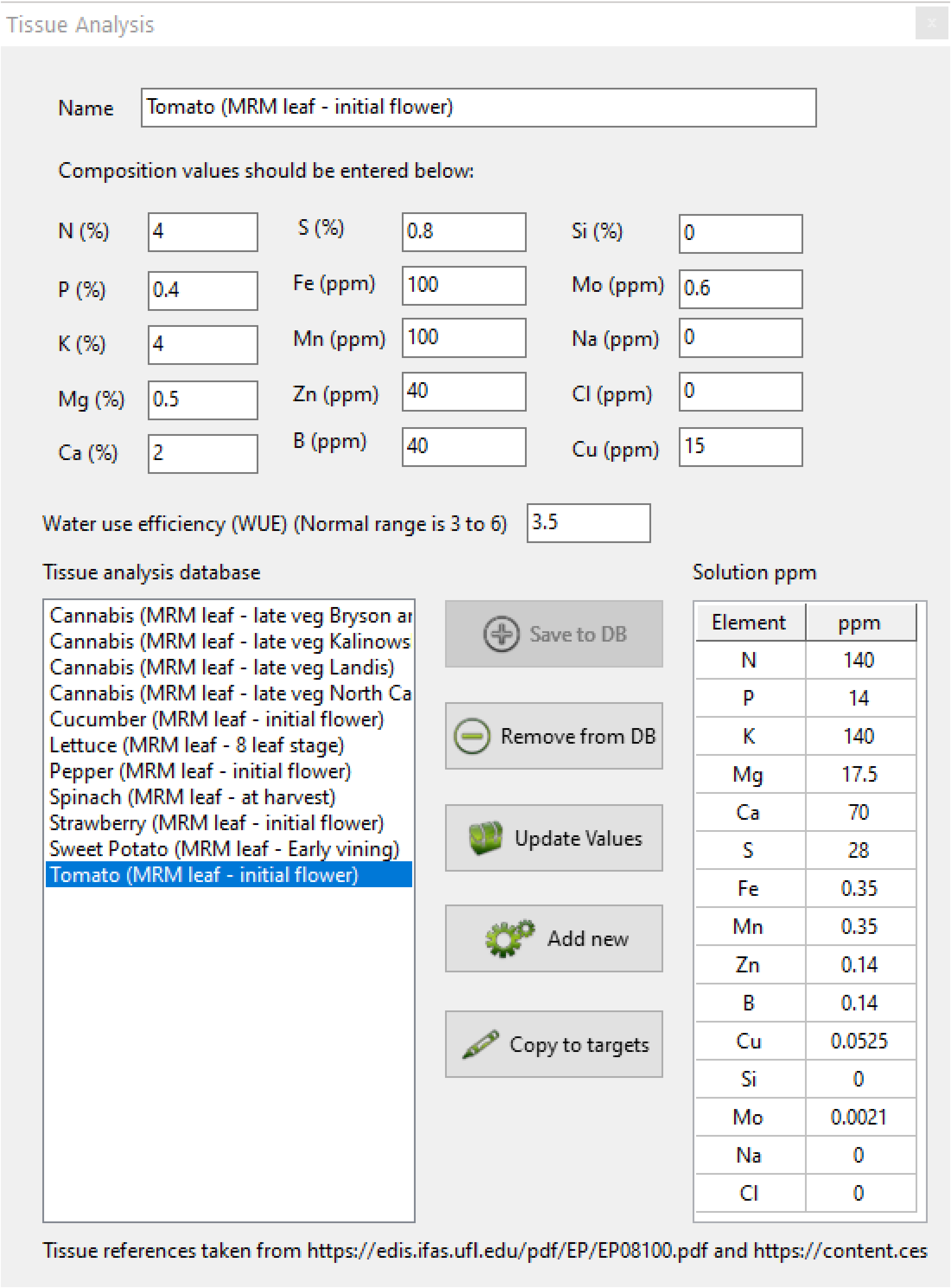
The volume of water required to grow a certain mass of tissue is called Water Use Efficiency (WUE). It is expressed as gram of tissue per liter of water transpired and has values from 3.0 to 6.0. Higher WUE values imply the plant is growing more efficiently, requires less water to grow the same mass of tissue, while a lower WUE implies the plant is less efficient and needs to transpire more to grow. Conditions that increase growing efficiency and decrease transpiration, such as carbon dioxide enrichment and high humidity, tend to increase WUE, while conditions that create inefficient growing – like low humidity with high temperature – tend to decrease it.

If we grow plants with a solution where we determine the nutrients according to the WUE and the concentrations in tissue we want, we can create very effective solutions that lower the probability of over accumulation of nutrients in the root zone and the solution. This allows for solutions that require no dumping and create very healthy plants in recirculating systems (for which Deep Water Culture, DWC, is the most common example).

Doing this process in HydroBuddy

From v1.99, HydroBuddy now includes a “Tissue Analysis” dialogue that allows you to use target tissue concentrations and a certain WUE value, to figure out what the required nutrient concentrations in a hydroponic solution would be like. The program also includes a small Database with tissue targets for certain plants and certain stages of development. There are also a couple of links that point you to resources where you can find a wide variety of different plant species and development stages if the ones that interest you are not included in the software’s default DB configuration.

The image below shows you an example where I determined the target solution concentrations required to grow a tomato plant that has the composition expected for a tomato plant in early flower.



Tissue Analysis

Name: Tomato (MRM leaf - initial flower)

Composition values should be entered below:

N (%): 4
P (%): 0.4
K (%): 4
Mg (%): 0.5
Ca (%): 2
S (%): 0.8
Fe (ppm): 100
Mn (ppm): 100
Zn (ppm): 40
B (ppm): 40
Si (%): 0
Mo (ppm): 0.6
Na (ppm): 0
Cl (ppm): 0
Cu (ppm): 15

Water use efficiency (WUE) (Normal range is 3 to 6): 3.5

Tissue analysis database

- Cannabis (MRM leaf - late veg Bryson ar
- Cannabis (MRM leaf - late veg Kalinows
- Cannabis (MRM leaf - late veg Landis)
- Cannabis (MRM leaf - late veg North Ca
- Cucumber (MRM leaf - initial flower)
- Lettuce (MRM leaf - 8 leaf stage)
- Pepper (MRM leaf - initial flower)
- Spinach (MRM leaf - at harvest)
- Strawberry (MRM leaf - initial flower)
- Sweet Potato (MRM leaf - Early vining)
- Tomato (MRM leaf - initial flower)

Solution ppm

Element	ppm
N	140
P	14
K	140
Mg	17.5
Ca	70
S	28
Fe	0.35
Mn	0.35
Zn	0.14
B	0.14
Cu	0.0525
Si	0
Mo	0.0021
Na	0
Cl	0

Tissue references taken from https://edis.ifas.ufl.edu/pdf/EP/EP08100.pdf and https://content.ces

Nutrient solution targets for a hydroponic solution to grow tomatoes with a leaf tissue composition equal to that expected for tomatoes under initial flower (MRM = most recent mature leaf). This assumes the WUE is 3.5 g/L.

How do I figure out the WUE?

As you can see, the above process requires you to input the WUE. This ranges from 3 to 6. It is not easy to measure in the environment, so the best practical solution is to assume your WUE is about 3.5 (the default value), prepare solutions with those concentrations and then observe how the EC of the solution changes as a function of time.

A solution that is prepared with a concentration that would be appropriate for the exact WUE of the plants will have an initial decrease in EC – as nutrients that are taken actively are rapidly taken up – followed by more stable to slightly decreasing EC conditions as uptake changes to be mostly passive. This cycle is repeated when solution is replenished to recover the initial volume in a recirculating system. A solution that is prepared too concentrated will have an increasing EC while a solution that is prepared too diluted will show a consistently decreasing EC. If your EC decreases more sharply with time then you need to assume a higher WUE, if your EC increases then you need to lower your WUE assumption.

Limits of the approach

While this approach can be very useful to create long lasting solutions, especially in recirculating systems, it suffers from some important limitations.

The first is that it doesn't account for changes in uptake due to changes in pH or availability in solution. This is the reason why the recommendations for elements like Fe and Mn, might be significantly lower than what you commonly see in nutrient solutions. In the above example, the solution requires only around 0.35ppm of Fe, but this means we need 0.35ppm of fully available Fe for the plant, which in reality might mean having 1.5ppm of Fe or more of added Fe, depending on the chemical form of Fe and the pH of the solution.

The above implies that values should not be used without considering the context and that this context might be much more important for some nutrients, for example micro nutrients, than for other elements, for example K and Ca, for which the availability windows and plant uptake are much more straightforward. The plant characteristics should also be taken into account. While a leaf tissue derived approach might only require 50 ppm of Ca in a lettuce crop, we know we need to feed more due to the poor water transport of this plant into new leaves.

Second, the approach assumes that all we care about is leaf composition. This is a perfectly fine if we are growing leafy greens, but if you’re growing a tomato plant, the composition will be heavily split between leaves and fruits as soon as flower pollination ends. For this reason, the nutritional needs of other important tissues – such as sink organs – should be considered very carefully when following this approach. In the case of tomatoes, this might mean feeding substantially higher levels of K, as this element has a much higher concentration in fruits than it has in leaves.

Crops that have changing nutritional needs due to changes in the composition of the tissue formed, require different nutrient solutions as a function of time, as we need to match the overall expected composition of the entire plant, not just the leaves.

Conclusions

Nutrient formulations do not need to be just trial and error. Up until now, besides a formulation database, HydroBuddy had no feature to help growers create formulations with any scientific basis. This new feature, introduces the ability to use target leaf tissue composition and WUE as a way to guide the initial formulation of nutrient solutions. While you still need experience to figure out when to overrule these values and increase or decrease concentrations, it does provide basic blue prints to build from. An analysis of how a formulation derived from tissue compares with your current formulation might also give you some insights into whether you are over or under feeding any elements.

Have you use the HydroBuddy’s leaf tissue analysis feature? Leave us some comments below!