Recent advances in the cultivation of CEA tomatoes: evidence from 2015-2025

Hydroponic tomato yields are already high, yet many operations still leak performance through nutrient scheduling, canopy design, and stress control. Below is a blunt, data-driven synthesis for controlled environments based on recent scientific studies. The pattern is consistent: stabilize nutrition and irrigation first, then layer biostimulants or hormones only where trials show a payoff.



A soilless cherry tomato crop. *Photo courtesy of Pakistan Hydroponics*. You can watch their farm here.

Mineral nutrition and solution management

A 2024 greenhouse study across six cultivars found that a constant nutrient concentration program matched yield and improved size distribution compared with stage-based ramps when EC was well controlled (1). A 2023 review distills

current best practice for recirculating systems, stressing stage-appropriate EC, ion ratios that avoid antagonisms, and disciplined monitoring in closed loops (2).

Closed systems are viable when sanitation and monitoring are tight. A greenhouse comparison showed closed hydroponics achieving similar yields with better water and fertilizer use efficiency than open run-to-waste setups (3). Calcium balance still matters. Whole-plant experiments showed that simply pushing calcium does not prevent blossom-end rot and that imbalances can backfire, so keep Ca adequate and balanced rather than excessive (4).

Irrigation and pruning practices that scale

Partial root-zone drying and moderate deficit irrigation remain the most defensible water-saving tactics in greenhouses. Grafted tomatoes under PRD or deficit regimes saved 30 to 40 percent water with only minor yield penalties and sometimes higher fruit mineral concentrations (5).

On canopy design, a low-truss high-density approach can raise kilograms per square meter. In a hydroponic sub-irrigated trial with the indeterminate hybrid Rebeca, the top treatment was two trusses per plant at 11.1 plants per square meter, reaching 22.61 kg per square meter in 134 days without harming fruit quality (6).

Biostimulants with signal, not hype

Seaweed extracts and chitosan have the most consistent tomato evidence in soilless systems.

A greenhouse study in inert substrates showed that foliar seaweed extract at 100 000 to 200 000 ppm improved chlorophyll, gas exchange, and fruit quality indices. Silicon

at 75 ppm (as sodium silicate) increased firmness and yield per plant in a palm-peat mix. Effects were substrate and dose dependent, so you must calibrate to your product and spray volume per area (7). A 2022 review synthesizes similar benefits for seaweed extracts under salinity stress, with gains tied to photosynthesis and ion homeostasis rather than magic bullets (8).

For chitosan, a 2025 greenhouse study on Floradade and Candela F1 tested 500, 1000, and 2000 ppm foliar programs. Higher rates improved growth and physiology, with cultivar-specific responses. Product specs like degree of deacetylation and molar mass were not reported, so do not assume equivalence across suppliers (9).

Exogenous hormones: targeted, not blanket

If fruit set is the bottleneck during heat or low pollen viability, exogenous hormones can help. In protected cultivation of cv. Srijana, a conservative foliar program of GA3 at 50 ppm with NAA at 25 ppm increased fruit set and total yield. The response surface penalized higher rates, reminding you that timing and dose are critical (10). For mechanism and limits, a 2022 review explains how auxin and gibberellin signaling induce parthenocarpy in tomato and why misuse leads to malformed fruit (11).

Summary tables

Table 1. Mineral nutrition and system practices with yield impact in CEA tomatoes

Factor	Cultivar or type	Dose or setting (ppm)	Observed effect	Source
Constant vs stage-based nutrient supply	Six cultivars, greenhouse	Program choice rather than dose	Constant feed matched yield and improved size distribution	(1)
Nutrient solution management review	General CEA	Program design	Best practice for EC, ion ratios, and closed-loop monitoring	(2)
Closed vs open hydroponics	Determinate tomato, greenhouse	System choice	Closed loop improved water and fertilizer efficiency with comparable yield	<u>(3)</u>
Calcium balance	Modern genotypes	Balanced Ca supply	Lower BER risk depends on overall ion balance, not brute Ca	(4)
Partial root-zone drying and deficit irrigation	Grafted tomato, greenhouse	Irrigation scheduling	30 to 40 percent water savings with minor yield penalties	<u>(5)</u>

Table 2. Biostimulants in soilless tomatoes

Biostimulant	Cultivar or type	Application	Dose (ppm)	Observed effect	Source
Seaweed extract	Cherry tomato, greenhouse substrates	Foliar	100 000 to 200 000	Improved physiology and fruit quality indices under stress	<u>(7)</u>
Silicon as sodium silicate	Cherry tomato, greenhouse substrates	Foliar	75	Increased firmness and yield per plant in palm-peat mix	<u>(7)</u>
Chitosan (medium MW, commercial)	Floradade and Candela F1	Foliar, multiple sprays	500, 1000, 2000	Improved growth and physiological performance, cultivar dependent	<u>(9)</u>
Seaweed extract review	Multiple tomato types	Seed or foliar in soilless culture	Various	Stress tolerance and modest yield gains under salinity	<u>(8)</u>

Table 3. Exogenous hormone programs with documented yield or set effects

PGR	Cultivar or type	Application	Dose (ppm)	Observed effect	Source
GA3 + NAA	Srijana, protected cultivation	Foliar during flowering	GA3 50, NAA 25	Increased fruit set and total yield; higher rates underperformed	(10)

PGR	Cultivar or type	Application	Dose (ppm)	Observed effect	Source
Auxin and GA context	Tomato, general	Mechanistic review	N/A	Explains parthenocarpy induction and risks of misuse	(11)

Practical takeaways

Do not chase clever ramps before you can hold EC steady. A constant, well-tuned feed can match yield and improve size distribution when the rest of the system is under control (1), (2). Closed loops pay only if you earn them with monitoring and sanitation (3). Low-truss high-density recipes push kg per square meter, provided irrigation and nutrition meet the faster sink demand (6). Seaweed extracts and silicon can help under stress, but responses are product and substrate specific. Chitosan works, yet cultivar and formulation matter, so trial first (7), (8), (9). Hormones are scalpels for set problems, not a replacement for climate and pollination management (10), (11).

How to easily lower the costs of your Athena nutrient regime

You can make your Athena schedule much cheaper by replacing the pH up products with simple raw salts. Branded pH management and buffering products like Athena Balance and Athena Pro Balance are, at their core, just sources of potassium bases delivered in carbonate or silicate form. They are however, very over priced for what they are and can be a high percentage of the overall cost of running these nutrient regimes. By understanding their labels and safety data sheets, we can replicate these formulations with commodity salts, achieving equivalent nutritional and pH adjusting outcomes at a fraction of the cost.



AgSil 16H, a very common base used to prepare potassium silicate solutions.

Athena Pro Balance can be replaced with Potassium Carbonate

The powdered Pro Balance product is likely nothing more than high-purity potassium carbonate (K_2CO_3), usually 98.5–100% pure. Chemically, K_2CO_3 contains ~68% K_2O -equivalent by weight, which is exactly what the Athena Pro Balance label reflects. This means you don't need to blend or dilute anything to make a replacement, simply sourcing food-grade or fertilizer-grade potassium carbonate is sufficient. You can dose it directly as you would the branded powder, bearing in mind it is strongly alkaline and should be added to water with care. Storage should be in sealed HDPE containers to avoid caking from atmospheric moisture.

Athena Blended Balance (liquid) can be replaced with an AgSil 16H solution

The liquid Balance label shows 2% K_2O . AgSil 16H, a common potassium silicate source, contains 32% K_2O and $\sim 53\%$ SiO_2 . To reproduce the K_2O content of Athena Balance, you need to dilute AgSil at the correct ratio:

- Target is 2% K₂O.
- Required fraction = 2 / 32 = 0.0625.
- This means 6.25% (w/w) AgSil in water.

Translated to a practical recipe, this equals 236.6 g of AgSil 16H per US gallon of solution (3.785 L), topped up with R0 water (must be R0 or distilled water). Dissolve the AgSil slowly with vigorous mixing, as potassium silicate is highly viscous and alkaline. The result is essentially identical in potassium concentration to the branded Balance, with the added benefit of supplying soluble silica (~1.55% Si in the solution).

Improving stability with KOH

One common issue with potassium silicate solutions is their tendency to polymerize or precipitate over time, especially at lower concentrations or in the presence of divalent cations. To mitigate this, adding a small amount of potassium hydroxide (KOH) helps maintain a strongly alkaline environment that discourages silica gelation. For the recipe above, adding 1 g of KOH per gallon of solution is a simple way to improve stability during storage. This will not significantly change the K_2O content but will keep the solution more stable and easier to handle.

Cost Analysis

Beyond the chemistry, cost is the main driver for making these substitutions. Let's look at a ballpark comparison based on typical retail prices (USD, 2025):

Product	Retail Price	Equivalent Raw Material	Raw Material Price	Cost per Gallon of Finished Equivalent
Athena Pro Balance (powder)	~\$7 per lb	Potassium carbonate	~\$2 per lb	Replacement is more than 3x cheaper
Athena Balance (liquid)	~\$20-40 per gallon	AgSil 16H + 1 g KOH	<pre>~\$6.4 per lb AgSil, ~\$5 per lb KOH (~3\$ AgSil + 1c of KOH per gal)</pre>	Replacement costs is around 10x cheaper

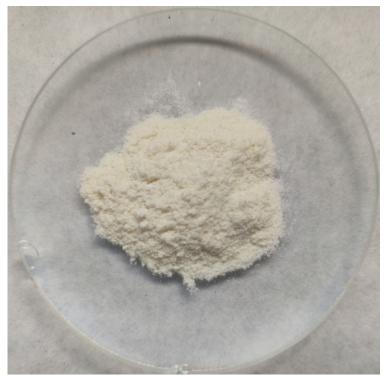
For the Balance liquid in particular, the price difference is striking: the branded gallon runs around \$20-40, while the equivalent solution made from AgSil 16H plus a pinch of KOH comes out to under \$3 per gallon, even at retail chemical pricing. The Pro Balance substitution is less dramatic in absolute terms but still represents substantial savings over time.

Take-home message

Replacing Athena Pro Balance is as simple as sourcing potassium carbonate, while Athena Balance can be reliably reproduced with a potassium silicate solution prepared from AgSil 16H plus a small stabilizing addition of KOH. For growers comfortable working with raw salts, this substitution strategy provides full control, predictable composition, and significant cost savings while providing a drop-in replacement for one of the most expensive parts of the Athena nutrient line.

Chitosan in hydroponic and soilless crops: what actually works

In hydroponic and substrate systems chitosan can help, but only inside fairly narrow windows of dose, molecular traits, and crop context. Here is what the strongest hydroponic and soilless evidence shows for common greenhouse crops, with doses in ppm and forms that have actually been tested in peer-reviewed trials.



Chitosan powder, used as a biostimulant in soilless cultivation

What matters before you dose

Form and solubility. Most horticultural studies use acid-solubilized chitosan, typically chitosan acetate prepared by dissolving chitosan in dilute acetic acid. Solubility improves as degree of deacetylation increases and molecular weight decreases. That changes biological activity and leaf

penetration, which is why not all chitosans behave the same in crops grown without soil. Review data across crops confirms that activity depends on origin, degree of deacetylation, molecular weight and derivative used, not just "chitosan" on the label (1).

Degree of deacetylation and molecular weight. Higher deacetylation increases positive charge density and solubility in the acidified sprays most growers use. Lower to mid molecular weight generally penetrates tissues better; very high molecular weight tends to act more at surfaces. Reviews focused on crop plants note these relationships and explain why different products show inconsistent results if DD and MW are not controlled (1).

Application route. Foliar and rootzone applications are not interchangeable. Foliar sprays in hydroponics commonly use 50 to 200 ppm for stress mitigation and quality endpoints. Rootzone dosing inside recirculating solutions can work for disease suppression at similar or higher ppm, but the tolerance window is tighter and crop-dependent. A 2024 root-focused review flags that root exposure can inhibit growth if dose and MW are off, even while defense responses go up (2).

Source. Commercial material is generally crustacean-derived, with fungal-derived chitosan available at smaller scale. Origin mainly matters through DD, MW and impurities like ash and protein. Again, agronomic performance maps back to those properties rather than source alone (1).

What the hydroponic and soilless studies actually show

Leafy greens and fruiting vegetables most

tested in soilless settings

- Lettuce, deep-flow hydroponics, foliar. In a controlled deep-flow system, foliar chitosan at 100 ppm mitigated salt stress, improved relative water content and chlorophyll, and reduced membrane damage markers. The trial used exogenous chitosan applied to leaves while plants grew in circulating nutrient solution, so the result is directly relevant to recirculating NFT or DFT growers (3).
- Cucumber, hydroponic rootzone, disease control. In a classic hydroponic study, adding 100 to 400 ppm chitosan to the nutrient solution suppressed Pythium aphanidermatum root rot and induced host defenses without visible phytotoxicity at those doses. This is one of the best-controlled demonstrations of rootzone efficacy in a soilless system (4).
- Tomato, soilless substrate, chitosan-based material at the rootzone. A soilless peat and perlite greenhouse system received a chitosan polyvinyl alcohol hydrogel with copper nanoparticles placed in the rootzone. The treatment improved growth, antioxidant capacity and yield relative to the untreated control. This is not a simple chitosan salt spray and the dose was delivered as a solid material rather than a ppm solution, but it shows chitosan-based materials can be integrated into substrate programs in practice (5).
- Context across crops. A comprehensive review of chitosan for plant protection and elicitation explains the defense activation seen above and why responses are dose and MW dependent. It also documents successful use patterns that generalize to greenhouse crops treated by foliar or root routes (6).

Practical dose ranges that align with the hydroponic evidence

If you want the odds on your side in hydroponics or inert substrates, stay inside these lanes and confirm on a small block first.

- Foliar, leafy greens and fruiting vegetables in hydroponics or inert substrate. 50 to 150 ppm per spray, usually every 7 to 10 days around stress periods. The deep-flow lettuce result sits at 100 ppm and delivered physiological benefits under salinity (3).
- Rootzone, recirculating hydroponics. 100 to 400 ppm in the circulating solution only when you have a clear disease target like Pythium in cucumber. For general biostimulation, root dosing is higher risk. The hydroponic cucumber study used 100 and 400 ppm to suppress Pythium effectively (4). Outside this range you are more likely to see growth penalties than benefits according to root-focused syntheses (2).
- Chemistry targets when purchasing. Prefer DD around 80 to 90 percent and low to mid MW material for foliar work. Verify supplier certificates rather than marketing bullets. The crop reviews explaining DD and MW effects are clear that these traits determine outcomes (1).

Summary tables

Table 1. Trials in hydroponic or soilless systems with chitosan

Crop	System	Application route	Chitosan form	Dose used (ppm)	Reported effect	Reference
Lettuce	Deep-flow hydroponics	Foliar spray	Acid-solubilized chitosan solution	100	Mitigated salinity stress, higher RWC and chlorophyll, lower oxidative damage	(3)
Cucumber	Hydroponics	Rootzone in nutrient solution	Chitosan solution in recirculating feed	100 to 400	Suppressed Pythium root rot, induced defense enzymes, no visible phytotoxicity at tested doses	(4)
Tomato	Soilless substrate, peat plus perlite	Rootzone material in substrate	Chitosan PVA hydrogel with Cu nanoparticles	not applicable as ppm	Improved growth, antioxidant capacity and yield versus control in substrate culture	<u>(5)</u>

Table 2. Chemistry traits that move the needle

Trait	Why it matters in soilless culture	Practical target
Degree of deacetylation	Higher DD increases solubility in dilute acids used for sprays and increases cationic charge for leaf interaction	80 to 90 percent DD for foliar sprays <u>(1)</u>

Trait	Why it matters in soilless culture	Practical target
Molecular weight	Lower to mid MW improves penetration and reduces viscosity. Very high MW can sit on surfaces and act mainly as an elicitor	Low to mid MW for foliar, avoid very high MW for root dosing (1)
Source	Crustacean and fungal sources both work. Performance depends on DD, MW and impurities, not source alone	Buy on spec sheet, not species label <u>(1)</u>

Table 3. Foliar versus root applications in hydroponics and substrates

Dimension	Foliar application	Root application
Typical working range	50 to 150 ppm per spray	100 to 400 ppm in the solution when disease control is the objective
Primary targets	Stress mitigation, quality traits, mild growth stimulation	Pathogen suppression in roots and elicitation of defenses
Risk profile	Low when DD and MW are appropriate and pH is controlled	Higher. Dose and MW errors can reduce root growth and yield
Evidence base in soilless settings	Deep-flow lettuce shows clear physiological benefits at 100 ppm (3)	Hydroponic cucumber shows robust Pythium control at 100 to 400 ppm (4)

How to deploy without shooting yourself in the foot

- 1. Start with foliar at 100 ppm on a small block. If your chitosan is low to mid MW and 80 to 90 percent DD, you are in the same ballpark as the effective lettuce hydroponic protocol (3).
- 2. Reserve root dosing for disease pressure. If you are chasing Pythium in cucumber, 100 to 400 ppm in the solution is supported. For general "growth promotion", root dosing is more likely to backfire than help in recirculating systems (4), (2).
- 3. **Verify product specs.** Ask for DD and MW. If the vendor will not provide them, find one who will. The variability you see in practice maps to those two numbers (1).
- 4. **Do not stack unknowns.** Mixing chitosan with copper, acids, or surfactants without a clear recipe can change activity. That can help in substrate programs where materials are embedded, as in the hydrogel example, but it is not a blank check (5).
- 5. **Measure the outcome that pays.** Run a side-by-side block with your limiting stress in view. If you cannot tie chitosan to a measurable gain in yield, quality or loss avoidance in your system, move on. Elicitation without payoff is just cost (6).

Iodine in Hydroponic Crops:

An Emerging Biostimulant

Introduction

Iodine sits in a weird spot in plant nutrition. It is essential for humans, not officially essential for higher plants, yet low, well chosen doses often push crops to perform better in controlled systems. The key is dose and form. Get either wrong and you tank growth. Get them right and you can see yield and stress-tolerance gains that are economically meaningful. Recent reviews lay out both the promise and the pitfalls, so let's cut through the noise and focus on agronomically relevant hydroponic and soilless work only. (1)



Potassium iodide, one of the most common forms used to supplement iodine in hydroponic culture.

Why iodine can behave like a

biostimulant

Mechanistically, iodine at trace levels appears to influence redox balance and stress signaling and can even become covalently bound to plant proteins. Proteomic evidence has shown widespread protein iodination, and plants deprived of iodine under sterile hydroponics grow worse until micromolar-range iodine is restored. That does not make iodine "essential" in the strict sense, but it explains why tiny doses can trigger outsized responses. (2)

Form matters

Across multiple hydroponic tests, iodide is absorbed faster and is more phytotoxic than iodate. In basil floating culture, growth was unaffected by roughly 1.27 ppm iodine as KI or 12.69 ppm iodine as KIO_3 , but KI above about 6.35 ppm iodine cut biomass hard, while KIO_3 needed far higher levels to do the same. That is a practical takeaway for nutrient solution design. Favor iodate when you are exploring a new crop or cultivar. (3)

Evidence from hydroponic and soilless crops

Lettuce

A classic water-culture study ran 0.013 to 0.129 ppm iodine in solution and saw no biomass penalty while leaf iodine rose predictably. Iodide enriched tissue more than iodate at equal iodine, which is useful if your target is biofortification, not just a biostimulant effect. (4)

Under salinity, iodate becomes more interesting. In hydroponic lettuce with 100 mM NaCl, about 2.54 to 5.08 ppm iodine as KIO_3 increased biomass and upregulated antioxidant metabolism,

which is exactly what you want in salty recirculating systems. Push higher and the benefits fade. (5)

Strawberry

Hydroponic strawberry responded to very low iodine. Iodide at or below 0.25 ppm and iodate at or below 0.50 ppm improved growth and fruit quality, while higher levels reduced biomass and hurt fruit quality metrics. You do not have much headroom here. (6)

Basil

Greenhouse floating culture trials on sweet basil showed cultivar-specific tolerance but the same pattern every time. KI starts biting growth above single-digit ppm iodine, while KIO_3 is far gentler at comparable iodine. Antioxidant capacity trends are cultivar dependent, so do not generalize "more phenolics" as a guarantee of better growth. (7)

Tomato

Tomato is where yield effects get real. In growth-chamber work, fertigation with iodate at roughly 6.35 to 12.69 ppm iodine increased fruit yield by about 30 to 40 percent in a small-fruited cultivar. In a greenhouse trial with a commercial hybrid, much lower iodine in solution, around 0.025 to 1.27 ppm as $\rm KIO_3$, still improved plant fitness and mitigated part of the salt penalty. Dose tolerance depends on the system and the genotype, so copy-pasting numbers between cultivars is a bad idea. (8)

Cabbage

Hydroponic Chinese cabbage tested 0.01 to 1.0 ppm iodine as KI or ${\rm KIO_3}$. Uptake and partitioning behaved differently by species and form. The practical read is that both forms work for biofortification within that band, but I would still lean

Working ranges seen in hydroponic or soilless trials

Crop	System	Iodine form used	Dose range tested in literature (ppm as I)	Observed direction of effect
Lettuce	Water culture	Iodide and iodate	0.013 to 0.129	Neutral on biomass, strong tissue enrichment at all doses tested
Lettuce under salinity	Hydroponic with 100 mM NaCl	Iodate	~2.54 to 5.08	Biomass increased, antioxidant system activation
Strawberry	Hydroponic	Iodide and iodate	Beneficial at or below 0.25 (I-) and 0.50 (IO3-)	Growth and fruit quality improved at low doses, declines above
Basil	Floating culture	Iodide and iodate	Safe near 1.27 as KI, 12.69 as KIO ₃ ; toxicity above ~6.35 as KI	KI far more phytotoxic than KIO₃ at equal iodine

Crop	System	Iodine form used	Dose range tested in literature (ppm as I)	Observed direction of effect
Tomato	Substrate fertigation and growth chamber	Iodate	~0.025 to 12.69 depending on setup	Yield and stress tolerance improved within study-specific bands
Cabbage	Hydroponic	Iodide and iodate	0.01 to 1.0	Both forms accumulated; response form- dependent

Practical setup that does not wreck a crop

Start with iodate. It is consistently less phytotoxic in solution culture than iodide at the same iodine level. Use iodide later only if you have a clear reason. (7)

Leafy greens

Conservative exploratory band: 0.03 to 0.10 ppm iodine in solution during vegetative growth. If you are running saline conditions, you can test up to about 2.5 to 5.1 ppm as iodate for stress mitigation, but do not do this blind outside a salinity trial. (4) (5)

Strawberry

Keep solution iodine low. Try 0.05 to 0.25 ppm as iodide or 0.10 to 0.50 ppm as iodate. Expect quality shifts alongside biofortification, and expect penalties if you push higher. (6)

Basil

If you work with KI, do not exceed about 1.3 ppm iodine without a reason and tight monitoring. With KIO3, you have

more headroom, but benefits are not guaranteed at the higher end. (7)

Tomato

In substrate systems, exploratory fertigation bands that have shown positive responses run roughly 0.025 to 1.27 ppm iodine as iodate for commercial cultivars. Higher doses around 6.50 to 12.50 ppm have improved yield in small-fruited genotypes under controlled conditions, but those are not starting points for a commercial house. (8)

Cabbage and other Brassicas

0.01 to 1.0 ppm works for biofortification trials in solution culture. Track form-specific uptake. (9)

Common failure modes

- 1. **Using iodide when you should have used iodate.** Iodide is more phytotoxic in water culture. If you switch to iodide, cut the ppm accordingly and watch plants closely. (7)
- Copying doses between crops or between stress contexts.
 Lettuce under salt stress tolerated and benefited from multi-ppm iodate that would be overkill in non-saline runs. (5)
- 3. Chasing biofortification at the expense of growth. Strawberry is very sensitive; the window for improvement is narrow and easy to overshoot. (6)
- 4. **Assuming universality.** Tomato shows real yield gains, but the best range depends on cultivar and system. Validate locally. (8)

Crop	Best form to start	Trial band to test next (ppm as I)	Notes you should not ignore
Lettuce	KIO₃	0.03-0.10 for routine runs; up to 2.5-5.1 only in salinity trials	Tissue enrichment is easy at sub-ppm; benefits need stress context
Strawberry	KI or KIO₃	0.05-0.25 as KI; 0.10-0.50 as KI03	Quality improved at low levels; penalties above
Basil	KIO ₃	0.5-3.0	KI becomes risky above low single digits
Tomato	KIO ₃	0.025—1.27 in commercial substrate; leave 6.5—12.5 to controlled trials	Verify by cultivar; watch fruit quality metrics
Cabbage	KIO ₃	0.05-0.5	Uptake is efficient; track partitioning by organ

Final word

Iodine can behave like a biostimulant in hydroponics and soilless systems, but only if you respect its razor-thin margin between helpful and harmful. Start small, prefer iodate, and validate on your own cultivars and systems instead of trusting a one-size-fits-all recipe. If you need a broader framework for running precise biofortification trials in soilless production, recent reviews are clear about why controlled systems are the right place to do this work. (9)

Cobalt in hydroponics as a biostimulant

People ask about dosing cobalt in recirculating systems to "stimulate" growth or flowering. For the crops that matter in hydroponics and soilless culture, peer-reviewed work does not show reliable growth or yield benefits from adding cobalt to the solution. What the literature does show is straightforward: cobalt is readily taken up at low ppm, it inhibits ethylene biosynthesis at pharmacological doses, and it becomes toxic fast when you push concentration. The burden of proof for agronomic benefit is still unmet. Below I summarize what high-quality studies in hydroponics and soilless systems actually report.



cobalt (II) chloride, the most common form of chloride used in studies

What cobalt does in plants

Cobalt is not established as essential for most higher plants. It is essential for N-fixing microbes and therefore matters in legumes, but for tomato, cucumber, lettuce and the like, its status is "potentially beneficial at very low levels, toxic at modest excess." A recent review frames this clearly and compiles transport and toxicity data across species (Frontiers in Plant Science, 2021).

A second, practical point is mechanism. Cobalt ions inhibit ACC oxidase, the last step in ethylene biosynthesis. That is why physiologists use cobalt chloride in short, high-dose treatments to suppress ethylene responses in experimental tissues. Classic work documents this inhibition in cucumber and other plants (Plant Physiology, 1976).

Ethylene inhibition can, in principle, delay senescence or alter stress signaling. The catch is dose. The amounts that clearly block ethylene in lab tissues are usually far above what you want sloshing around a long-cycle greenhouse system, and benefits rarely translate to whole plants under production conditions.

What happens in hydroponics and soilless systems

Tomato

Nutrient solution exposure, subtoxic range

Tomato grown hydroponically with cobalt at 0.30 ppm and 1.18 ppm showed strong root retention and limited shoot transfer. This is uptake behavior, not a biostimulant response, and the authors did not report yield benefits. The forms used were cobalt(II) salts in solution culture (Environmental Science & Technology, 2010).

Toxicity under higher exposure

A hydroponic study imposed severe cobalt stress at 23.57 ppm and observed depressed biomass, disrupted water status, chlorophyll loss and oxidative damage in tomato. Cobalt was supplied as cobalt chloride in the nutrient media. Plant

growth regulators mitigated symptoms but did not make cobalt itself beneficial (Chemosphere, 2021).

Lettuce

Toxicity in greenhouse hydroponics with inert media

Iceberg lettuce grown in a perlite based hydroponic system suffered growth and pigment losses at **11.79 ppm** cobalt. Cobalt was added as cobalt salt to a modified Hoagland solution. The same paper showed nitric oxide donor treatments could blunt the damage, which again argues cobalt at this level is a stressor, not a stimulant (<u>Chilean Journal of Agricultural Research</u>, 2020)

Cucumber

Mechanistic ethylene work, not production benefit

Multiple peer-reviewed studies in cucumber use cobalt chloride as an ethylene biosynthesis inhibitor in explants or short assays. These demonstrate the mechanism but are not agronomic validations for dosing cobalt into a recirculating system for weeks (Plant Physiology, 1976; Forests, 2021).

Summary table of relevant studies in hydroponics and soilless culture

Crop	System	Cobalt form	Solution cobalt (ppm)	Exposure description	Main outcome
Tomato	Aerated nutrient solution	Co(II) in solution culture	0.30 and 1.18	Whole plants in controlled hydroponics	Strong root retention, limited shoot transport; no biostimulant effect reported. ES&T 2010 PubMed

Crop	System	Cobalt form	Solution cobalt (ppm)	Exposure description	Main outcome
Tomato	Hydroponic solution, stress test	Cobalt chloride	23.57	Whole plants, growth regulators tested for mitigation	Marked toxicity: biomass and chlorophyll decreased, oxidative stress increased. Chemosphere 2021
Lettuce	Perlite + recirculating solution	Cobalt salt in modified Hoagland	11.79	Greenhouse hydroponics with inert media	Significant growth and pigment losses at this dose; NO donor partially mitigated damage. Chilean J. Agric. Res. 2020
Cucumber	Short mechanistic assays	Cobalt chloride	used as ethylene inhibitor in short assays	Explants or detached tissues	Confirms ethylene inhibition by Co ²⁺ ; not a production recommendation. Plant Physiology 1976

So is cobalt a biostimulant in hydroponic vegetables

For tomato, cucumber and lettuce grown hydroponically or in soilless culture, peer-reviewed journal data do not support cobalt as a legitimate biostimulant input. You can inhibit ethylene transiently with cobalt chloride in lab tissues, but that is not a recipe for higher yield in a recirculating system. The agronomic studies that actually dose solutions

show either neutral responses at sub-ppm levels or clear toxicity when you push into low double digits. The general biology context from a recent cobalt review matches this picture and does not contradict it (<u>Frontiers in Plant Science</u>, 2021).

Practical guidance for hydroponic and soilless growers

Default practice

Do not add cobalt intentionally to non-legume hydroponic recipes. There is no reproducible benefit and real risk of toxicity in the low tens of ppm, with lettuce showing damage already at ~12 ppm and tomato at ~24 ppm under hydroponic conditions. (see here, or here)

If you want to experiment

Keep total cobalt in solution at **sub-ppm** levels and treat it as a research trial, not a production strategy. Track solution cobalt with ICP if you can. The only peer-reviewed hydroponic tomato data near this range are **0.30 to 1.18 ppm**, which documented transport behavior, not stimulation.

Forms used in the literature

Cobalt chloride is the dominant form when researchers test ethylene inhibition or impose cobalt stress. Cobalt sulfate also appears in some soilless protocols. Neither form has peer-reviewed evidence of yield stimulation in hydroponic tomato, cucumber or lettuce. (see here or here)

Legumes are the exception

Cobalt matters indirectly via N-fixing symbionts. If you are growing legumes in soilless systems, cobalt management belongs in the microbial nutrition discussion, not as a general biostimulant for non-legumes (see here).

Crop	"Stimulant" claim in journals	Reported beneficial window	Toxicity begins around	Notes
Tomato	None in hydroponic journals	None demonstrated	~23.6 ppm in nutrient solution	Sub-ppm exposures documented uptake with no benefit. ES&T 2010; Chemosphere 2021
Lettuce	None in hydroponic journals	None demonstrated	~11.8 ppm in nutrient solution	Damage includes biomass and chlorophyll loss in greenhouse hydroponics. Chilean J. Agric. Res. 2020
Cucumber	Mechanistic ethylene inhibition only	Not applicable	Not defined for production, lab tissues often use high short- term doses	CoCl ₂ used to block ethylene in explants; not a production recommendation. Plant Physiology 1976

Bottom line

If you grow tomato, cucumber or lettuce in hydroponics or inert media, cobalt is not a proven biostimulant. At sub-ppm levels you might see nothing. Push it into the low tens of ppm and you will see toxicity. The only unequivocal "effect" you can count on is ethylene inhibition during short, high-dose laboratory treatments with cobalt chloride, which is not a

safe or sensible production tactic. Until robust, peer-reviewed hydroponic trials show yield or quality gains at practical ppm, the rational move is to leave cobalt out.

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 and here and here 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.

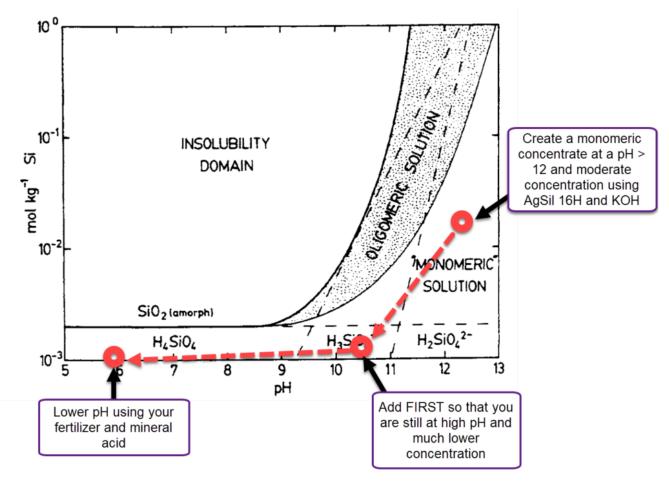
Second, we have **acid stabilized silicon products**. These are products like PowerSi Classic and OSA28. These products are always liquids and contain monosilicic acid in an acidic environment, with stabilizing agents added to prevent the polymerization of the monosilicic acid.

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.



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.

$$+ H_{2}O \longrightarrow H_{3}C \longrightarrow$$

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

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.

T.	I		I		I
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 <u>create sensor stations</u> and how to <u>calibrate them</u>. 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.

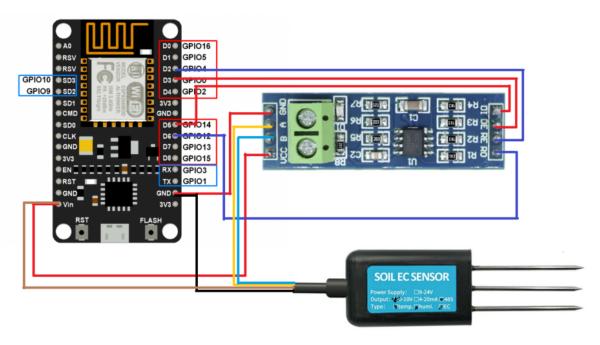


Diagram showing cable connections between moisture content sensor NodeMCUv3 and communication board.

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 <u>ESP Software serial library</u> 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, 0
0 \times 00, 0 \times 00};
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 |</pre>
sensorResponse[4]);
               float soil temp = 0.1 * int(sensorResponse[5] << 8</pre>
sensorResponse[6]);
                       int soil ec = int(sensorResponse[7] << 8</pre>
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;
                            soil bulk permittivity
                  float
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(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);
}
```

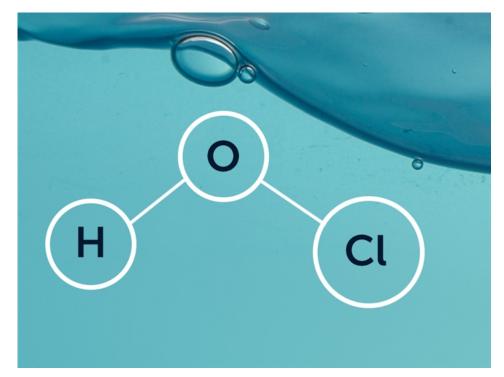
Note that RE and DE are not placed on digital pins 2 and 3, as other pins in the NodeMCUv3 carry out other functions and the board will not initialize if it has the RS485-to-TTL communicator connected through those pins. The R0 and RI pins are connected to digital pins D5 and D6, this is because in the 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		
Flora Pro Grow	56	25	0.029	
Flora Pro Micro	56	25		
Athena pro core	180	25		
Athena Pro Gro	180	25	0.183	
Athena Pro Bloom	180	25		
Masterblend 5-11-26	59	25	0.024	
Calcium Nitrate	37	50	0.024	

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

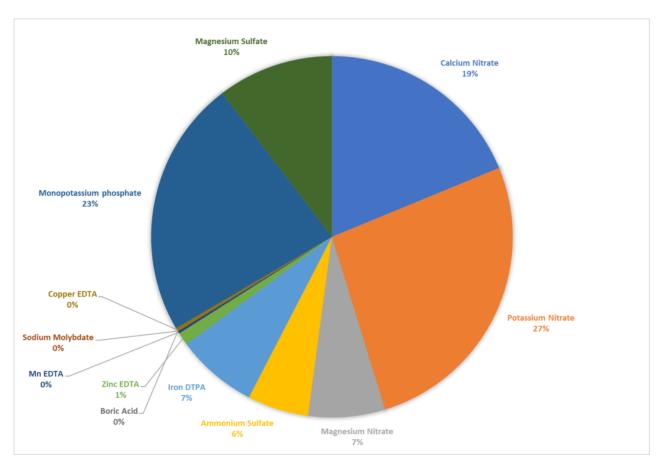
It is also interesting to consider the case of raw fertilizer inputs as this allows us to better think about formulations to reduce cost and also calculate whether making custom fertilizers is worth the expense. The table below shows you some commonly used bulk fertilizer inputs, their cost in USD and 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 this formulation is around 0.016 USD/gal. 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 able tο diminish this bе 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 nobrainer. 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 <u>my youtube channel</u> or read <u>my blog articles</u> 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

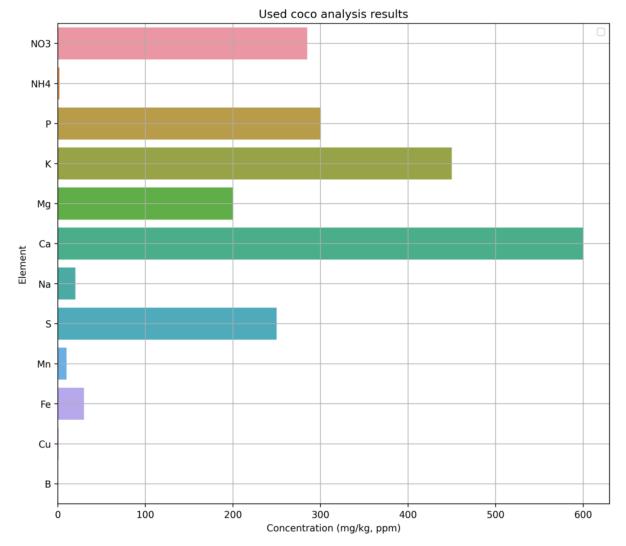
Reusing media is not without peril. When media is pristine, it is more predictable. You know its basic composition and you can feed it the same set of nutrients and hope to obtain very similar results. Nonetheless, after media goes through a growing cycle, its chemical composition changes and the starting 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 1.5 m S/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 1.5 m S/cm we return to feeding our normal regime. The idea here is that while the media is above 1.5 m S/cm the plant can take all the nutrients it needs from the media, but once the media EC drops below 1.5 m S/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 $\mathrm{NO_3}$) 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!