Using Portable Low-Cost Chlorophyll Sensors to Assess Plant Health and Improve Crop Quality in Hydroponics

When you grow plants hydroponically you become responsible for delivering the exact amount of every essential nutrient. Getting nitrogen right is particularly challenging since plants can require dramatically different amounts depending on their growth stage. Traditional methods to assess nitrogen status require sending leaf samples to a lab, which is expensive, destructive, and provides results too late to make timely corrections. Portable chlorophyll meters offer a practical solution.

A DIY chlorophyl meter compared to some commercial alternatives (taken from (9)).

What Are Portable Chlorophyll Meters?

Portable chlorophyll meters are handheld devices that non-destructively estimate the chlorophyll content in plant leaves. The most widely used device is the SPAD-502 meter, which works by measuring light transmission through a leaf at two wavelengths: 650 nm (red light, which chlorophyll absorbs) and 940 nm (infrared, which chlorophyll does not absorb). The device calculates a dimensionless SPAD value based on the transmission ratio (1). Since 50-70% of leaf nitrogen is contained in chlorophyll molecules, these readings provide a reliable proxy for nitrogen status (2).

These meters are particularly useful in hydroponic systems where you have complete control over nutrient delivery and can make rapid adjustments when deficiencies are detected. Research has demonstrated strong correlations between chlorophyll meter readings and nitrogen status in major hydroponic crops including tomato (3), lettuce (4), and greenhouse vegetables (5).

Major Advantages

The primary advantage is that measurements are instantaneous and non-destructive. You can measure the same leaf repeatedly throughout the growing season without harming the plant. This is especially valuable in hydroponics where you might want to monitor nitrogen status weekly or even daily during critical growth periods.

The correlation between SPAD readings and leaf nitrogen concentration is typically very strong. In romaine lettuce grown in soilless culture, SPAD readings showed correlation coefficients of $R^2 = 0.90$ with nitrogen concentration and $R^2 = 0.97$ with chlorophyll content (4). Similar results have been

reported for greenhouse tomatoes, where R^2 values ranged from 0.86 to 0.94 (6).

Unlike laboratory analysis, chlorophyll meters provide immediate feedback. When you detect that SPAD readings are dropping below your target range, you can adjust your nutrient solution that same day, particularly advantageous in fertigation systems (7).

Low-Cost Alternatives

The SPAD-502 meter typically costs $2,000-$2,600, which can be prohibitive for small growers. Several low-cost alternatives have been developed and validated. The atLEAF meter costs around $200-$300 while providing equivalent performance (8). Studies found strong correlations (R^2 = 0.96) between SPAD and atLEAF meters across multiple crop species (8).

Functional chlorophyll meters can even be built from scratch using simple electronic components for under $100. A recent study described construction using 3D-printed hardware and off-the-shelf LEDs and photodiodes that achieved strong correlations with both the SPAD-502 and atLEAF meters (9).

Device	Cost (USD)	Wavelengths (nm)	Key Features
SPAD-502	2,000-2,600	650, 940	Industry standard
atLEAF+	200-300	660, 940	Data logging, SPAD conversion
MC-100	400-600	653, 931	Larger measurement area
Custom Arduino	<100	650, 940	Requires assembly

The atLEAF meter is available through agricultural supply retailers, while various manufacturers offer devices in the $100-$300 range through online platforms.

Research in Hydroponic Crops

Chlorophyll meters have been successfully used to guide nitrogen management in various hydroponic crops. In tomato production, using SPAD readings to trigger nitrogen applications resulted in the highest yields compared to fixed-rate applications, with improved nitrogen use efficiency (3). Researchers established critical SPAD values for different physiological stages, allowing growers to apply nitrogen only when needed.

For lettuce grown in high tunnels with fertigation, both SPAD and atLEAF meters accurately estimated nitrogen status, fresh weight, and chlorophyll concentration with R^2 values above 0.90 (4). Research on basil with different nitrogen rates showed that SPAD, atLEAF, and MC-100 meters all provided reliable estimates with R^2 values of 0.93-0.98 (10).

Important Limitations

While valuable, chlorophyll meters have limitations growers need to understand. The relationship between SPAD readings and actual nitrogen content can vary between species. Research on seven crop species found that while the relationship between SPAD and chlorophyll content was consistent, the relationship between SPAD and leaf nitrogen varied widely (1). You cannot use the same threshold values across different crops.

Environmental factors also affect readings:

- **Time of day**: Chloroplast movement can cause SPAD readings to decrease by 13-28% at midday under low nitrogen conditions (1). Take readings in early morning or maintain consistent measurement times.
- **Light history**: Short-term changes in growth light affect nitrogen allocation to chlorophyll (1).
- **Leaf position and age**: Chlorophyll content varies across

leaf positions and with age. Always measure the same leaf position.

Chlorophyll meters provide relative rather than absolute measurements. To use them effectively, you need to establish calibration curves for your specific crop and growing conditions.

Best Practices

Establish Baseline Values: Grow plants at different nitrogen levels and measure both SPAD readings and leaf nitrogen concentration via lab analysis. This establishes your calibration curve.

Use Reference Strips: Maintain a section of plants receiving optimal nitrogen. Compare readings from your bulk crop to these reference plants. If bulk readings drop more than 5-10% below reference, increase nitrogen delivery (7).

Standardize Protocol: Always measure the same leaf position. For leafy greens, measure the most recently fully expanded leaf. For tomatoes, measure leaflets on the leaf closest to the most recent fruit cluster. Take measurements at the same time daily, preferably early morning (5).

Take Multiple Readings: SPAD readings can vary 10-15% between individual plants. Measure at least 20-30 plants per zone and use the average (7).

Species-Specific Calibration: If you grow multiple crops, establish separate calibration curves for each.

Crop	Optimal Range	Action Threshold	Measurement Location
Lettuce	35-45	<32	Youngest fully expanded leaf

Crop	Optimal Range	Action Threshold	Measurement Location
Tomato	45-55	<42	Leaflet near newest fruit cluster
Cucumber	40-50	<37	3rd fully expanded leaf
Basil	35-45	<32	Terminal leaves

Note: These are general guidelines. Establish specific thresholds for your cultivars through calibration with lab analysis.

Conclusions

Portable chlorophyll meters represent an excellent investment for hydroponic growers optimizing nitrogen management. Low-cost alternatives make this technology accessible even for hobby growers. While these devices have limitations related to species-specific calibration and environmental factors, following standardized protocols allows effective use for management decisions.

The key is understanding that chlorophyll meters provide relative measurements. Take time to establish proper baseline values for your crops and conditions. Once calibrated, these devices help fine-tune nitrogen delivery, reduce fertilizer waste, prevent deficiencies, and improve crop yield and quality.

For growers ready to adopt this technology, starting with an atLEAF meter or similar low-cost device provides an affordable entry point with performance comparable to expensive options.

The Problems with Brix Analysis of Sap in Crops

Brix analysis, the measurement of soluble solids in plant sap using a refractometer, has gained popularity as a quick field test for assessing plant health and crop quality. The method is appealingly simple: squeeze some sap from a leaf onto a refractometer, and within seconds you get a number that supposedly tells you how healthy your plant is. Many proponents claim that plants with high brix readings are more resistant to pests and diseases, while low readings indicate nutritional problems. However, when we examine the scientific literature surrounding brix measurements in plant sap, particularly for agronomically important crops in hydroponic or soilless systems, we find that this technique has substantial limitations that are often overlooked.

A refractometer, the most common tool to measure brix of plant sap.

The Appeal and the Theory

The basic premise of brix analysis is straightforward. The refractometer measures the refractive index of a solution, which correlates with the concentration of dissolved solids (1). In plant sap, these dissolved solids include sugars, amino acids, proteins, minerals, and other organic compounds. The theory suggests that healthier plants with better nutrition will have higher sugar content from improved photosynthesis, leading to higher brix readings (2). While this sounds reasonable, the reality is far more complex.

Problem 1: Dramatic Diurnal Variation

One of the most significant issues with brix measurements is their extreme variability throughout the day. Plants accumulate sugars during photosynthesis in the light period and then mobilize these sugars at night for growth, respiration, and transport to sink organs. Research on mature oak trees showed that total leaf sugars increased by an average of 16 mg/g dry weight during the day and returned to baseline at night (2). This represents substantial diurnal fluctuation that can produce 30% or more variation in brix readings depending on time of day (3).

Studies on maize have shown that starch and soluble sugars in leaves follow predictable diurnal patterns, with soluble carbohydrates peaking in the afternoon and reaching their minimum before dawn (3). The timing of peak brix values varies by species and growing conditions. Some plants show maximum sugar accumulation at midday, while others peak in the afternoon (2). This means that a brix reading taken at 10 AM might be dramatically different from one taken at 3 PM on the same plant, even though the plant's nutritional status has not changed.

Weather conditions further complicate matters. Plants have been observed to move sugars to roots in anticipation of storms, sometimes days in advance, causing brix readings to drop substantially even though the plant is not experiencing nutritional stress. Water stress also affects readings, as dehydration concentrates dissolved solids and artificially elevates brix values without indicating better plant health.

Problem 2: Spatial Variation Within Plants

The location where you sample sap makes an enormous difference in the reading you obtain. Research has consistently shown large differences in sugar content between young and old leaves, with old leaves often having substantially different concentrations than new growth (2). In reproductive plants, leaves near fruits typically show the lowest brix readings because fruits have high nutritional demands and act as strong sinks for sugars and other nutrients.

This spatial heterogeneity means that two technicians sampling the same plant but choosing different leaves could easily obtain readings that vary by 50-70%. Without strict standardization of which leaf to sample, when during its development, and from which position on the plant, brix measurements become nearly impossible to compare across samples or over time.

The Logistical Challenge

For brix analysis to be useful as a management tool, it requires an extraordinary level of commitment and consistency. You would need to collect samples at different locations on each plant, within different areas of your growing system, under different weather conditions, and critically, at exactly the same time of day, multiple times per week (4). Because of

this inherent variability, effective use requires managing trends rather than individual measurements. Most growers simply do not have the bandwidth to develop the degree of familiarity needed with brix readings for it to become a truly reliable diagnostic tool.

What Brix Cannot Tell You

Perhaps most importantly, even if you could control for all the temporal and spatial variation, brix readings provide very limited actionable information. A low brix reading tells you that soluble solids are low at that moment, but it does not tell you why. Is it a nitrogen deficiency? Phosphorus? Calcium? Is it a problem with root function? Temperature? Light intensity? Water relations? The brix value alone provides no way to differentiate between these possibilities.

Additionally, brix measurements tell you nothing about immobile nutrients like calcium and boron, which do not move readily through the sap. These nutrients are critical for cell wall formation, disease resistance, and fruit quality, yet they remain essentially invisible to brix analysis.

A Better Alternative: Leaf Tissue Analysis

When growers need reliable information about plant nutritional status in hydroponic systems, leaf tissue analysis provides a far more comprehensive and actionable alternative. Unlike brix analysis, which measures only mobile compounds in sap at a single moment, tissue analysis quantifies the total accumulated concentrations of both mobile and immobile nutrients in plant tissues (4).

Tissue analysis provides specific concentration values for nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, and all essential micronutrients. These values can be compared

against established sufficiency ranges for your specific crop, allowing you to identify which nutrients are deficient, adequate, or excessive. This specificity enables targeted corrective actions rather than guesswork.

While tissue analysis does require sending samples to a laboratory and waiting for results, it provides a stable measurement that is far less affected by time of day or recent environmental fluctuations. Modern labs can return results within days, and the interpretive frameworks for tissue analysis are well-established across hundreds of crop species.

Comparison Factor	Brix Analysis	Tissue Analysis
Time of day sensitivity	Very high (30-70% variation)	Low
Spatial variation within plant	Very high	Moderate
Nutrients detected	Soluble solids only (mostly sugars)	All essential elements (15+)
Specificity	Non-specific	Element-specific
Interpretation	Difficult without extensive experience	Well-established sufficiency ranges
Cost per sample	Low	Moderate
Actionable information	Limited	Comprehensive

Practical Recommendations

This is not to say that refractometers have no place in crop monitoring. For specific applications like determining harvest timing for fruits or monitoring sugar accumulation in reproductive organs, brix can be useful. However, for assessing the overall nutritional health of vegetative crops

in hydroponic systems, the limitations of sap brix analysis are substantial.

If you are serious about optimizing nutrition in your hydroponic operation, invest in regular tissue analysis rather than relying on brix readings. Sample the most recently matured leaves at consistent growth stages, submit samples to a reputable agricultural laboratory, and use the results to make informed adjustments to your nutrient formulation and delivery. This approach will provide you with reliable, actionable data that can actually improve your crops, rather than numbers that fluctuate wildly based on time of day and sampling location.

The appeal of a quick field test is understandable, but in the case of brix analysis for plant health assessment, the simplicity comes at the cost of reliability and utility. Sometimes the best tools are not the fastest ones, and when it comes to understanding what your plants need, there is no substitute for comprehensive analysis.

Comparing Nutrient Solutions for Hydroponic Strawberry Production

Getting the right nutrient solution for strawberries in hydroponics can feel like trying to solve a puzzle where every piece matters. Unlike many crops where you can get away with a generic formula, strawberries are particularly responsive to nutrient composition, especially when it comes to the balance between nitrogen and potassium. Today, we will explore how different nutrient formulations affect both yield and fruit

quality in soilless strawberry production.

A hydroponic strawberry production greenhouse

The Modified Steiner Approach

When researchers at the Technological Institute of Torreón tested different nitrogen and potassium combinations in strawberries, they discovered something important about how these two nutrients interact. Using a (1) modified version of Steiner's Universal Nutrient Solution, they evaluated twelve different formulations with nitrogen ranging from 126 to 210 ppm and potassium from 195 to 430 ppm.

The results were revealing. Plants receiving 168 ppm nitrogen combined with 430 ppm potassium achieved yields of 114 grams per plant, which was significantly higher than lower nitrogen treatments. However, here is where it gets interesting: while high nitrogen boosted yield, it actually decreased fruit quality. The highest soluble solids content (10.5 degrees Brix) occurred at the lowest nitrogen level of 126 ppm. This creates a real dilemma for growers who want both high yields and premium quality fruit.

Solution Type	N (ppm)	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	Yield	Quality Impact
Modified Steiner (Low N)	126	46	195	449	121	89.3 g/plant	Highest Brix (10.5°)
Modified Steiner (Medium N)	168	32	273	360	97	108 g/plant	Moderate Brix (10.0°)
Modified Steiner (High N)	210	19	194	413	111	111 g/plant	Lowest Brix (9.5°)

The Critical Role of Potassium

What emerged from this study was potassium's profound impact on fruit quality. When potassium was increased to 430 ppm, the soluble solids climbed to 10.6 degrees Brix, and phenolic compounds reached their peak as well. The (1) research showed that the optimal combination for maximizing both yield and nutraceutical quality was 168 ppm nitrogen with 430 ppm potassium, resulting in antioxidant capacity of 6305 microequivalents of Trolox per 100 grams.

This makes physiological sense. Potassium plays a fundamental role in sugar transport through the phloem, and when potassium availability is adequate, more sugars accumulate in the fruit. Meanwhile, excessive nitrogen tends to promote vegetative growth and the synthesis of nitrogen containing compounds like proteins and amino acids, rather than the accumulation of secondary metabolites that contribute to fruit quality.

Optimizing NPK Ratios for Chinese

Greenhouses

A comprehensive study from China Agricultural University took a different approach by examining the combined effects of nitrogen, phosphorus, potassium, and water on strawberry production. Using a (2) quadratic regression design with 36 treatments, researchers determined that nitrogen was by far the most important factor, followed by water, then phosphorus, with potassium having the least impact on the sweetness to acidity ratio.

Their optimal formulation for achieving yields above 110 grams per plant with excellent fruit quality included nitrogen at 156 to 172 ppm (supplied as calcium nitrate), phosphorus at 54 to 63 ppm (as sodium dihydrogen phosphate), and potassium at 484 to 543 ppm (from potassium sulfate). This represents significantly higher potassium levels than the Steiner based formulations, suggesting that when other nutrients are optimally balanced, strawberries can benefit from even more potassium.

Nutrient	Optimal Range (ppm)	Impact on Yield	Impact on Quality (SSC/TA)
Nitrogen (N)	156 to 172	Most significant positive effect	Most significant factor
Phosphorus (P)	54 to 63	Moderate positive effect	Second most important
Potassium (K)	484 to 543	Significant positive effect	Minimal impact
Water	12.0 to 13.1 L/plant	Second most important	Third most important

The Calcium and Electrical Conductivity Question

While much attention focuses on NPK ratios, calcium concentration matters enormously in strawberry production. In the modified Steiner solutions, calcium ranged from (1) 244 to 449 ppm depending on the treatment. Higher calcium levels corresponded with lower nitrogen and potassium concentrations, maintaining appropriate osmotic potential.

Research has shown that the electrical conductivity (EC) of the nutrient solution significantly impacts strawberry performance in soilless culture. Studies using different EC levels found that (3) 1.3 mS/cm was optimal for spring production, while 2.2 mS/cm proved better during winter months. This seasonal adjustment reflects the plant's changing water use and nutrient demand patterns throughout the growing cycle.

Micronutrient Considerations

While macronutrients get most of the attention, micronutrient composition matters too. The (1) modified Steiner formulations included iron at 5 ppm, manganese at 1.6 ppm, boron at 0.865 ppm, zinc at 0.023 ppm, copper at 0.11 ppm, and molybdenum at 0.048 ppm. These concentrations remained constant across all treatments, suggesting that within reasonable limits, macronutrient balance has a more pronounced effect on yield and quality than micronutrient variation.

Making Practical Choices

So what should you actually do with this information? If you are growing strawberries hydroponically and want to maximize both yield and quality, consider starting with a solution containing approximately 160 to 170 ppm nitrogen, 55 to 60 ppm

phosphorus, and 400 to 500 ppm potassium. Maintain the K:Ca ratio near 1-1.4:1 and the K:Mg ratio near 4:1. This matches some of my previous publications on the K:Ca ratio.

Remember that these recommendations assume you are maintaining appropriate pH (around 5.5 to 6.0) and EC levels suitable for your growing conditions. The (2) research demonstrated that excessive nutrients actually decreased both yield and quality, so more is definitely not better. You will need to adjust based on your specific cultivar, climate, and growing system, but these ranges provide a solid starting point backed by peer reviewed research.

The key takeaway is that strawberry nutrition in hydroponics requires a delicate balance. While nitrogen drives yield, potassium enhances quality, and the interaction between these two nutrients determines your ultimate success. Monitor your plants carefully, conduct tissue analysis when possible, and do not be afraid to adjust your formulation based on what the plants are telling you.

Comparing Nutrient Solutions for Hydroponic Tomatoes

When growing tomatoes hydroponically, one of the most critical decisions you'll make is choosing the right nutrient solution. The composition of your nutrient solution can dramatically affect both the quantity and quality of your harvest. In this post, I'll examine different nutrient formulations that have been tested in scientific studies and discuss how they impact tomato production in soilless systems.

Picture of a soilless tomato greenhouse

Understanding Nutrient Solution Basics

Before diving into specific formulations, it’s important to understand that tomato plants have changing nutritional needs throughout their growth cycle. Research has shown that early in the season, excessive nitrogen can cause plants to become too vegetative, resulting in bullish growth that produces misshapen fruits and increases susceptibility to disease (1). High potassium levels can also create problems by interfering with calcium and magnesium absorption, leading to blossom end rot.

Most successful nutrient programs divide the growing season into distinct stages. The seedling stage requires lower concentrations of nutrients, particularly nitrogen, while mature fruiting plants need substantially higher levels of most nutrients to support both vegetative growth and fruit development (2).

Comparing Two Common Formulations

Research has established several effective nutrient formulations for hydroponic tomatoes. I'll compare two well documented approaches that represent different philosophies in nutrient management.

Nutrient	Arizona Formula (Seedling)	Arizona Formula (Fruiting)	Florida Formula (Early)	Florida Formula (Late)
Nitrogen (N)	113 ppm	144 ppm	60 to 70 ppm	150 to 200 ppm
Phosphorus (P)	62 ppm	62 ppm	39 ppm	39 ppm
Potassium (K)	199 ppm	199 ppm	200 ppm	300 to 400 ppm
Calcium (Ca)	122 ppm	165 ppm	150 to 200 ppm	150 to 200 ppm
Magnesium (Mg)	50 ppm	50 ppm	48 ppm	48 ppm

The Arizona formulation (2) maintains relatively consistent macronutrient levels between growth stages, with only modest increases in nitrogen and calcium as plants mature. In contrast, the Florida approach (1) uses much lower nitrogen during early growth to prevent bullishness, then dramatically increases both nitrogen and potassium during fruit production.

Micronutrient Requirements

While macronutrients often receive the most attention, micronutrients are equally essential for healthy tomato production. These elements remain fairly constant throughout the growing cycle (2). Standard micronutrient concentrations for hydroponically grown tomatoes include iron at 2.5 ppm, manganese at 0.62 ppm, boron at 0.44 ppm, zinc at 0.09 ppm,

copper at 0.05 ppm, and molybdenum at 0.06 ppm.

Micronutrient	Concentration (ppm)
Iron (Fe)	2.5
Manganese (Mn)	0.62
Boron (B)	0.44
Zinc (Zn)	0.09
Copper (Cu)	0.05
Molybdenum (Mo)	0.06

The Impact of Nitrogen Supply on Quality

Research on nitrogen management has revealed some surprising findings. A study examining nitrogen supply at different growth stages found that increasing nitrogen from 140 to 225ppm during the vegetative stage increased protein, vitamin C, and sugar content in fruits (3). However, the effect on lycopene and beta-carotene depended heavily on the potassium supply during the reproductive stage.

Other research examining lower nitrogen levels has shown that minimal nitrogen supply can actually enhance lycopene content in tomato fruits, particularly when coupled with sufficient water supply (4). Studies in hydroponic culture have demonstrated that either the lowest or medium levels of nitrogen application produced the best lycopene content, suggesting that optimal nitrogen levels for antioxidant production may be lower than those for maximum yield.

Potassium's Role in Fruit Quality

Potassium plays a fundamental role in determining tomato fruit quality. Research has demonstrated that increasing potassium supply during the reproductive stage significantly enhances

sugar concentration, vitamin C content, protein levels, lycopene, and beta-carotene in tomato fruits (3). The effect is particularly pronounced when potassium levels increase from 200 to 500ppm.

Another comprehensive study found that high proportions of potassium in the nutrient solution increased quality attributes including fruit dry matter, total soluble solids content, and lycopene content (5). However, these same researchers found that high proportions of calcium improved tomato fruit yield and reduced the incidence of blossom end rot, highlighting the importance of balancing these two nutrients.

Electrical Conductivity Management

One of the most innovative approaches to nutrient management involves carefully controlling the electrical conductivity (EC) of the nutrient solution. A study in closed NFT (Nutrient Film Technique) systems examined three different EC replacement set points: 5, 7.5, and 10 mS/cm (6). Remarkably, the highest EC replacement set point produced yields equivalent to lower EC treatments while significantly improving fruit quality.

The higher EC replacement threshold resulted in better dry matter content and total soluble solids in berries. Additionally, it demonstrated superior environmental sustainability by reducing total nutrients discharged into the environment by 37% compared to the medium EC treatment and 59% compared to the low EC treatment (6). This approach challenges conventional thinking about salinity stress in tomato production.

Calcium Management and Blossom End

Rot

Calcium nutrition presents one of the most common challenges in hydroponic tomato production. Blossom end rot, characterized by dark lesions on the blossom end of fruits, results from calcium deficiency in developing fruits. However, this deficiency often occurs even when calcium levels in the nutrient solution appear adequate (1).

The problem frequently stems from antagonism between nutrients. Excessive potassium in the nutrient solution can interfere with calcium uptake by plant roots. This is particularly problematic early in the season when using pre-mixed fertilizers that contain high potassium levels. Growers working with water containing less than 50 ppm calcium need to be especially cautious about potassium concentrations.

To minimize blossom end rot, it's critical to maintain calcium levels between 150 and 200 ppm while keeping early season potassium levels moderate. Some growers supplement calcium nitrate with calcium chloride to increase calcium availability without adding more nitrogen. Each pound of calcium chloride (36% Ca) in 30 gallons of stock solution increases calcium concentration by approximately 14 ppm in the final nutrient solution when injected at a 1% rate (1).

Effects on Yield and Quality Parameters

The differences between nutrient formulations can significantly impact both yield and fruit quality. Research consistently shows that inadequate nitrogen during fruiting stages produces lower yields, though the fruits may have better sugar content and flavor. Conversely, excessive nitrogen can produce abundant foliage at the expense of fruit production (4).

Potassium levels have a pronounced effect on fruit quality parameters. Adequate potassium improves fruit firmness, color development, and sugar content (3). However, excessive potassium can lead to calcium and magnesium deficiencies that compromise both yield and quality.

The timing of nutrient adjustments also matters significantly. Studies have shown that gradually increasing nutrient concentrations as plants transition from vegetative to reproductive growth produces better results than sudden changes in formulation. Plants that experience consistent, appropriate nutrition throughout their lifecycle typically show improved yields and more uniform fruit quality (6).

Practical Considerations

When implementing a nutrient program, several practical factors deserve consideration. Water quality plays a fundamental role in determining how much of each nutrient to add. Wells in many regions naturally contain significant calcium and magnesium, sometimes providing 40 to 60 ppm calcium (1). These naturally occurring nutrients should be factored into your formulation calculations.

The pH of your nutrient solution also affects nutrient availability. Research has established that maintaining pH between 5.5 and 6.0 ensures optimal nutrient uptake (2). Water with high alkalinity requires acidification, which can be accomplished using phosphoric acid or sulfuric acid depending on your phosphorus requirements.

The type of hydroponic system you're using may also influence your nutrient concentrations. Systems requiring fewer daily irrigation cycles may need higher nutrient concentrations to ensure plants receive adequate nutrition. The general principle is that nutrient concentrations should be higher in systems with less frequent fertigation compared to those with continuous or very frequent feeding (1).

Advanced Management: The Transpiration-Biomass Ratio

One of the most sophisticated approaches to nutrient management involves calculating a recovery solution based on the transpiration-biomass ratio (6). This method recognizes that the relationship between water use and dry matter production changes throughout the growing cycle.

Research has shown that the transpiration-biomass ratio is high early in the crop cycle (approximately 300 liters per kilogram of dry weight), decreases during mid-season to a relatively stable phase, and then increases again late in the season (up to 400 liters per kilogram). This pattern suggests that nutrient concentrations should be adjusted accordingly: lower concentrations in the first and last phases, and higher concentrations during the middle phase when biomass accumulation is most rapid.

Conclusion

Successful hydroponic tomato production requires careful attention to nutrient solution composition. While several proven formulations exist, the research clearly shows that no single approach works best for all situations. The Florida formulation with its conservative early nitrogen levels may be ideal for preventing bullishness in greenhouse production, while higher EC strategies can improve fruit quality in closed systems.

Key takeaways from the scientific literature include: maintain nitrogen between 60 and 70 ppm early in the season to prevent excessive vegetative growth, increase potassium substantially during fruiting to enhance quality parameters, keep calcium between 150 and 200 ppm throughout the season while monitoring potassium levels to prevent antagonism, and consider that

higher EC values (up to even 10 mS/cm) may be feasible limits for nutrient solution replacement in recirculating systems.

Starting with a well researched base formulation and making careful adjustments based on plant response, tissue analysis, and your specific growing conditions provides the most reliable path to optimizing both yield and quality in your hydroponic tomato crop. The scientific evidence demonstrates that nutrient management is not a one-size-fits-all proposition, but rather a dynamic process that should respond to both plant developmental stage and environmental conditions.

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pH vs Nutrient Availability: Rethinking the Classic Charts

If you've been around hydroponics long enough, you've probably seen the ubiquitous "pH vs nutrient availability" chart. It usually looks like a series of colored bars, each showing how available a nutrient supposedly is across a pH range. The bars are wide for some nutrients at certain pH values, narrow for others, and the chart often comes with a moral: keep your solution pH between 5.5 and 6.5.

I discussed some of these issues in a previous post, but it's worth revisiting them here with a clearer chart. The problem is that most of these charts trace back to soil agronomy research from the 1930s and 1940s. They're not based on solution chemistry relevant to hydroponics. They conflate microbial activity, lime chemistry, and plant physiology with solubility. And, in some cases, they are flat out misleading.

Let me talk about why the traditional chart is wrong, what

modern chemistry tells us, and how a more honest representation looks.

Where the Old Charts Went Wrong

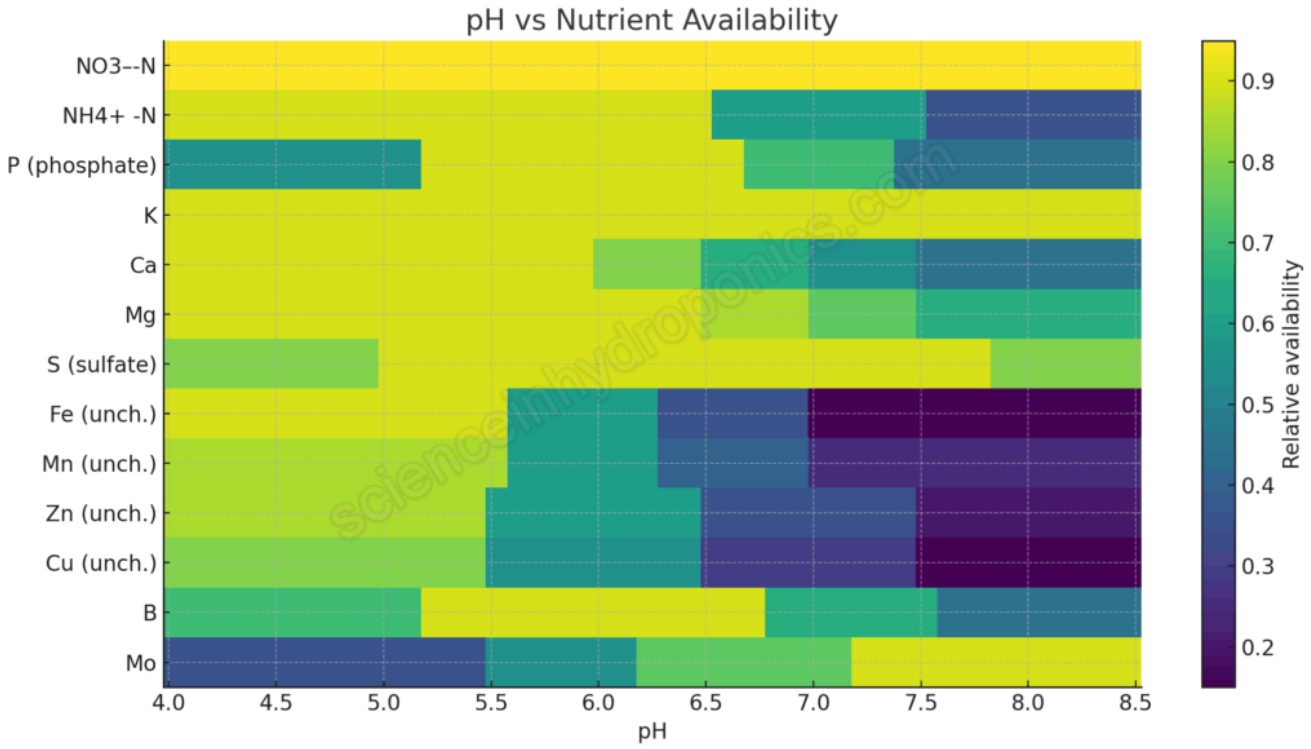
The historical diagrams were designed for soils, not hydroponic solutions. For example:

- **Nitrate (NO_3^-)**: In many charts, nitrate availability appears to fall off at low pH. In reality, nitrate is completely soluble across any reasonable pH range. The "loss" in those charts comes from soil microbial nitrification shutting down under acidic conditions, not relevant when you're directly dosing nitrate salts in solution.
- **Calcium (Ca) and Magnesium (Mg)**: Old charts show Ca and Mg as always available at high pH. But that ignores precipitation with phosphate or carbonate, which can start as low as pH 6.2 for Ca. The old charts show high Ca and Mg availability at high pH because the high pH in soils was usually achieved by the addition of dolomite or lime, which greatly increased Ca and Mg concentrations in soil, this is not the case in a soilless setup.
- **Micronutrients (Fe, Mn, Zn, Cu)**: These are shown as less available above neutral pH, which is true for unchelated forms (they hydrolyze and precipitate quickly). But in hydroponics, I typically use chelates, and their stability extends availability well above pH 7.
- **Phosphorus (P)**: Charts often suggest a broad plateau around pH 6 to 7. In truth, phosphate solubility is sharply influenced by calcium concentration and carbonate alkalinity. The idea of a universal "wide bar" is misleading.

These errors matter. They lead growers to overemphasize the magic 5.5 to 6.5 range without appreciating that different nutrients behave differently, and that chelation or precipitation risks can change the picture entirely.

Building a Better Chart

To improve on the old diagrams, I constructed a new heatmap. Instead of arbitrary bar widths, each nutrient's relative availability (scaled from 0 = low to 1 = high) is modeled based on actual solubility, speciation, and chelation chemistry. The chart covers pH 4.0 to 8.5.



Updated chart I created for nutrient availability in soilless systems based on chemical and plant physiology principles

This chart is not an absolute quantitative prediction (real world systems have variations depending on concentration, alkalinity, chelate type, etc.). But it captures the *directional chemistry* more honestly. For nutrients that are effectively pH independent (like nitrate), the line is flat.

For those that crash with pH (like unchelated iron), the line drops. And for Ca and Mg, I’ve introduced tapering to reflect phosphate precipitation behavior.

Nutrient by Nutrient Ranges

Here’s a summary table describing the approximate pH behavior, the range of best availability, and the underlying reason:

Nutrient	Broad Availability Range	Notes / Reason
NO_3^--N	4.0 to 8.5	Soluble across all relevant pH; uptake independent of pH in hydroponic solution. Old charts confused microbial nitrification with solubility.
NH_4^+-N	Best <6.5; declines >7.0	At higher pH, conversion to unionized NH_3 increases, which is less available and potentially toxic.
Phosphorus (P)	Peak 5.5 to 6.5; drops <5.2 and >7.0	Solubility falls at high pH due to Ca+P precipitation (starting ~6.2); also limited at low pH by fixation and speciation.
Potassium (K)	4.0 to 8.5	Monovalent cation, highly soluble, minimal precipitation issues (sometimes K containing silicates at higher pH values)
Calcium (Ca)	Stable <6.0; declining >6.2	Precipitates with phosphate and carbonate as pH rises; availability falls gradually above ~6.2.

Magnesium (Mg)	Stable <6.5; mild decline >7.0	Mg+P precipitation is less aggressive than Ca+P; solubility loss is slower but still possible at higher pH.
Sulfate (SO_4^{2-})	Broad 4.5 to 8.0	Generally soluble. At very low pH, some soils can adsorb sulfate due to protonated variable charge surfaces, reducing availability. At very high pH, reduced root uptake efficiency and competition with other anions can occur; in concentrated Ca^{2+} + SO_4^{2-} systems gypsum may precipitate by saturation.
Iron (Fe, unchelated)	Max <5.5; falls sharply >6.0	Fe^{3+} hydrolyzes and precipitates as hydroxides and oxides above ~pH 6; nearly unavailable by pH 7.
Manganese (Mn, unchelated)	Best <6.0; declining >6.3	Mn^{2+} oxidizes and precipitates above neutral pH.
Zinc (Zn, unchelated)	Best <6.0; low >7.0	Zn^{2+} solubility decreases with increasing pH; precipitates as hydroxide/carbonate.
Copper (Cu, unchelated)	Best <6.0; poor >7.0	Cu^{2+} strongly hydrolyzes, falls out of solution quickly with rising pH.
Boron (B)	Best 5.5 to 6.8	Boric acid is readily available in this range; at higher pH, more borate forms, reducing uptake.

Molybdenum (Mo)	Improves >6.0	Molybdate solubility increases with pH; plants often deficient in acidic conditions, more available at neutral/alkaline pH.

The Ca vs Mg Difference

A key improvement over older charts is distinguishing calcium from magnesium. While both can precipitate with phosphate, their behaviors differ:

- **Ca+P** precipitation is strong and begins around pH 6.2, especially in solutions with 1 to 3 mM phosphate. Brushite, dicalcium phosphate, and hydroxyapatite phases progressively reduce solubility.
- **Mg+P** precipitation is slower and less pronounced. Mg^{2+} is more strongly hydrated and less eager to form insoluble phosphates. It tends to stay soluble longer, only declining gently above pH 7.

Chelation: The Missing Dimension

My chart above shows unchelated forms. In real hydroponics, Fe, Mn, Zn, and Cu are almost always chelated. Depending on the chelate (EDTA, DTPA, EDDHA, HBED), stability can be maintained up to pH 7.5 to 9. This dramatically extends availability, particularly for Fe. A separate chart is needed to show chelated behavior.

Why This Matters

So why obsess about getting this chart right?

Because oversimplified charts lead to oversimplified thinking. If you believe nitrate solubility collapses below pH 6, you might panic when your reservoir drifts to 5.2, even though NO_3^- is unaffected. If you believe Ca is “always available,” you might miss that phosphate precipitation is happening in your tank right now at pH 6.3. And if you don’t distinguish between chelated and unchelated micronutrients, you’ll misdiagnose deficiencies.

A better chart isn’t just about scientific pedantry. It’s about helping growers make better decisions: when to acidify, when to buffer, when to choose a stronger chelate, and when to worry (or not worry) about a drifting pH.

Final Thoughts

The classic nutrient pH charts had their place in teaching basic agronomy 80 years ago. But hydroponics deserves more precision. Nutrients don’t all behave the same way. Some are flat across the entire range (NO_3^-, K). Some rise or fall gradually (B, Mo, Mg). Others are brutally sensitive (Fe without chelates). And precipitation interactions mean that Ca and phosphate availability are tied together, not independent.

This new heatmap and the accompanying table aren’t the last word, they’re a more honest starting point. **The real message is: understand the chemistry, not just the cartoon.**

Can you manage downy mildew in hydroponic basil with organic foliar sprays?

Basil downy mildew, caused by the obligate oomycete *Peronospora belbahrii*, has become one of the most serious diseases affecting hydroponic and greenhouse basil production globally. The pathogen, first documented in Europe in 2001 and later detected in the United States in 2007, requires high relative humidity (at least 85%) or wet leaves to infect plants (1). Temperature preferences favor moderate conditions around 20°C rather than higher temperatures, which explains why the disease thrives in controlled environment systems where leaf wetness and humidity are difficult to manage (1).

Downy mildew in basil shows characteristic black marks on the underside of leaves

Understanding the infection process is critical for designing effective spray programs. Under conditions of continuous free moisture, sporangia germinate within 3 to 5 days by producing germ tubes that penetrate basil leaves directly through the epidermis, typically without entering through stomata (2).

Seven days after initial infection, sporangiophores bearing new sporangia emerge through stomata on both the upper and lower leaf surfaces, creating secondary inoculum that spreads rapidly throughout greenhouse facilities (2). This relatively short cycle from infection to sporulation means that preventive measures must start before visible symptoms appear.

Multiple field trials evaluating organic fungicides have delivered sobering results for growers seeking alternatives to conventional chemistry. A comprehensive study testing products approved for organic production, including copper octanoate, hydrogen dioxide, sesame oil, neem oil, thyme oil, citric acid, *Bacillus* species, and *Streptomyces lydicus*, found that none were effective at controlling downy mildew when applied to susceptible basil cultivars (3). Applications were made weekly starting before symptom development, and efficacy was assessed based on incidence of symptomatic leaves rather than severity, reflecting the zero tolerance for disease on fresh market herbs (3). A summary of the tested fungicides and their effectiveness is shown on the following table.

Product (Active Ingredient)	**Mode of Action**	**Effectiveness**
Cueva (Copper octanoate)	Contact fungicide, disrupts enzyme function	Ineffective
OxiDate (Hydrogen dioxide)	Oxidizing agent, contact action	Ineffective
Organocide (Sesame oil)	Physical barrier, suffocation	Ineffective
Trilogy (Neem oil)	Physical barrier, azadirachtin content	Ineffective
Forticept EP #1 (Thyme oil)	Essential oil, contact action	Ineffective

Product (Active Ingredient)	Mode of Action	Effectiveness
Procidic (Citric acid)	pH modulation, contact action	Ineffective
Actinovate (*Streptomyces lydicus*)	Biocontrol, competitive colonization	Ineffective
Companion (*Bacillus subtilis*)	Biocontrol, induced resistance	Ineffective
Double Nickel (*B. amyloliquefaciens*)	Biocontrol, antibiosis	Ineffective
Regalia (*Reynoutria sachalinensis*)	Plant defense activator	Ineffective

The limited efficacy of organic fungicides appears related to the aggressive nature of the pathogen and the difficulty of achieving thorough foliar coverage in dense basil canopies. Even when combined with resistance inducers or natural products, organic treatments failed to provide commercially acceptable levels of disease suppression (5).

Environmental management offers more promise than chemical sprays alone. Light suppresses sporulation of *P. belbahrii*, with continuous light or supplemental lighting during nighttime hours substantially reducing spore production (6). Growers can exploit this by maintaining photoperiods longer than 13 hours or by using low-intensity supplemental lighting during dark periods. Reducing leaf wetness duration is equally important because the pathogen requires at least 24 hours of continuous moisture for infection and dense sporulation (7). In hydroponic systems, switching from overhead misting to sub-canopy irrigation and increasing air movement with horizontal airflow fans can dramatically reduce infection pressure (8).

Temperature manipulation provides another non-chemical tool. Passive heat treatment using transparent plastic covers to raise greenhouse temperatures during sunny periods suppressed

downy mildew development without damaging basil plants (9). Temperatures above 30°C inhibit sporangiophore formation and sporangial germination, though plants must be acclimated gradually to avoid heat stress. This approach works best in greenhouse operations with sufficient ventilation control and may be less practical in open hydroponic facilities.

Varietal resistance remains the most effective long-term strategy for hydroponic basil growers. Breeding efforts have identified resistance sources in wild basil species *Ocimum americanum*, and these traits have been successfully transferred into sweet basil backgrounds (10). Commercial varieties with improved resistance are now available, though complete immunity has not been achieved. Growers should prioritize these resistant cultivars and combine them with environmental controls rather than relying on organic fungicide sprays.

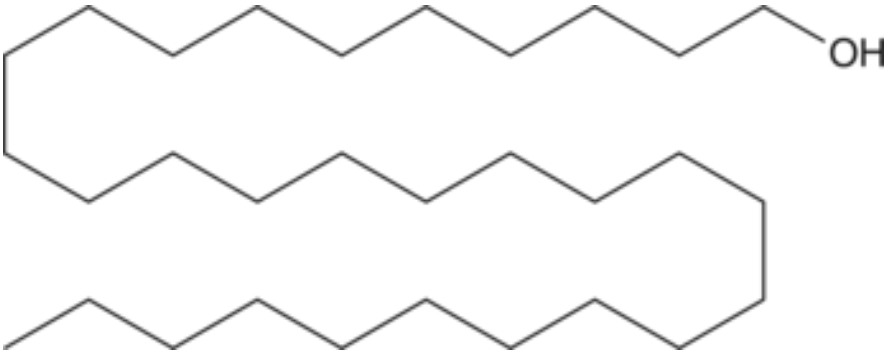
Cropping system modifications can reduce disease pressure in organic systems. Research on open field organic production found that sparse sowing density combined with resistant varieties provided better control than chemical treatments alone (11). In hydroponics, maintaining wider plant spacing, particularly in NFT or DWC systems where humidity tends to be higher, allows better air circulation and faster leaf drying after irrigation events.

The reality for hydroponic basil producers is that organic foliar sprays, when used alone, will not provide adequate downy mildew control on susceptible varieties. The pathogen's rapid lifecycle, preference for humid greenhouse conditions, and resistance to contact fungicides makes chemical intervention largely ineffective without supporting measures. Successful organic management requires integrating resistant varieties, environmental manipulation (particularly light, humidity, and leaf wetness control), appropriate plant spacing, and vigilant monitoring for early disease detection. Growers who continue relying primarily on organic sprays

should expect continued losses, while those who adopt integrated approaches combining genetics and environment will achieve better results.

Triacontanol Foliar Sprays in Soilless Culture: Formulation and Application

Triacontanol is a naturally occurring long-chain fatty alcohol found in plant cuticle waxes that can act as a growth regulator at very low concentrations. Below I focus on peer-reviewed evidence for triacontanol in hydroponic and soilless systems, with attention to preparation methods, yield effects, and quality outcomes in tomatoes, cucumbers, strawberries, and lettuce.



Above you can see a representative model of triacontanol. Chemically triacontanol is a long-chain fatty alcohol, very hard to dissolve in water and apply effectively to plants.

Evidence for Yield and Quality Effects

Hydroponic lettuce. Foliar application of triacontanol at

10^-7 M (approximately 0.043 mg/L) to 4-day-old hydroponically grown lettuce seedlings increased leaf fresh weight by 13-20% and root fresh weight by 13-24% within 6 days. (1) When applied at both 4 and 8 days after seeding, leaf area and mean relative growth rate increased by 12-37%. There was no additional benefit from repeating applications beyond two sprays in this short-cycle crop.

Tomato in hydroponic systems. Weekly foliar applications of 70 µM triacontanol (approximately 21 mg/L) on tomatoes grown in hydroponic drip systems significantly increased flower number by 37-50% and total fruit number by 22-57%, resulting in a 28% higher total yield at harvest. (2) Individual fruit weight decreased by 16%, but the net effect on total productivity remained positive. The treatment advanced blooming without affecting plant height or internode number, demonstrating a specific effect on reproductive development.

Cucumber under soilless conditions. Foliar application of triacontanol at 0.8 mg/L on cucumber genotypes under salt stress improved photosynthesis, stomatal conductance, and water use efficiency. (3) The treatment enhanced antioxidant enzyme activities and maintained better membrane stability. Yield traits, including fruit number and average fruit weight, improved in response to triacontanol application. Salt-tolerant genotypes (Green long and Marketmore) showed greater responsiveness than sensitive genotypes.

Strawberry. Triacontanol has shown promise in improving drought tolerance in strawberry plants by enhancing growth, productivity, and physiological performance, though most work has been conducted in soil rather than true soilless systems. (4)

Formulation: Creating a

Concentrated Stock Solution

Triacontanol has extremely low water solubility (less than 1 mg/L at room temperature), which makes proper formulation critical. The most reliable approach combines an organic solvent with a surfactant to create a stable concentrate that can be diluted into spray solutions.

Stock Solution Protocol

Materials needed:

- Triacontanol powder (90%+ purity)
- Ethanol (95% or higher)
- Tween-20 or Tween-80 (polysorbate surfactant)
- Distilled or deionized water
- Glass or high-density polyethylene containers

Preparation of 1000 mg/L (1000 ppm) stock:

1. Weigh 1000 mg of triacontanol powder using an analytical balance.
2. Dissolve the triacontanol in 100 mL of 95% ethanol in a glass beaker. Warm gently (35-40°C) while stirring with a magnetic stirrer for 15-20 minutes to ensure complete dissolution. Do not exceed 50°C.
3. Add 5 mL of Tween-20 to the ethanol solution and mix thoroughly for 5 minutes. This surfactant concentration (0.5% v/v in final volume) ensures proper emulsification and leaf surface wetting.
4. Transfer the ethanol-triacontanol-surfactant mixture to a 1000 mL volumetric flask.
5. Bring to final volume with distilled water while mixing continuously. The solution will appear slightly cloudy due to micelle formation, which is expected and desirable.

6. Store the stock solution in an amber glass bottle at room temperature. The stock is stable for 3-4 months when protected from light and heat.

Alternative solvent systems: Some studies have successfully used isopropanol or acetone as solvents. (5) However, ethanol provides the best combination of triacontanol solubility, plant safety, and ease of handling for growers.

Working Solution Preparation

Dilute the 1000 mg/L stock to achieve target concentrations based on crop and growth stage:

Lettuce: Dilute 1:10,000 to 1:20,000 for final concentrations of 0.05-0.1 mg/L. For a 1-liter spray bottle, add 0.05-0.1 mL of stock solution.

Tomato: Dilute 1:50 for final concentration of 20 mg/L. For a 1-liter spray bottle, add 20 mL of stock solution.

Cucumber: Dilute 1:1250 for final concentration of 0.8 mg/L. For a 1-liter spray bottle, add 0.8 mL of stock solution.

Add an additional 0.1% v/v Tween-20 (1 mL per liter) to the final spray solution to ensure maximum leaf coverage and absorption. This additional surfactant enhances uptake without phytotoxicity when concentrations remain below 0.2%. (3)

Application Timing and Frequency

Seedling stage: Apply once at 4-8 days after emergence for leafy greens in short-cycle production. A single early application is often sufficient for lettuce. (1)

Vegetative and reproductive stages: For fruiting crops like tomato and cucumber, apply weekly starting 4 weeks after transplant and continuing through flowering and early fruit

set. Three to five applications total are typically used. (2) (3)

Application method: Apply using a hand sprayer or backpack sprayer with a cone nozzle, ensuring complete leaf coverage including undersides. Apply in early morning or late afternoon to maximize absorption and minimize evaporation. Spray until runoff just begins.

Reported Effects Across Crops

Crop	Concentration	Application schedule	Yield effect	Quality effect	Reference
Lettuce (hydroponic)	0.043 mg/L	Once at day 4, optional repeat at day 8	Fresh weight +13-20%, leaf area +12-37%	Not assessed	(1)
Tomato (hydroponic drip)	21 mg/L	Weekly from week 4 through fruit set	Total yield +28%, fruit number +22-57%	Minimal changes in soluble solids, lycopene, vitamin C	(2)
Cucumber (soilless, salt stress)	0.8 mg/L	Three sprays: 72h after stress, at flowering, at fruit maturity	Improved fruit number and weight under stress	Maintained lower electrolyte leakage, higher chlorophyll	(3)

Mechanisms and Considerations

Triacontanol acts through a secondary messenger system involving 9-L(+)-adenosine, which triggers rapid ion influx (Ca^{2+}, K^{+}, Mg^{2+}) and modulates gene expression related to

photosynthesis, hormone balance, and stress responses. (2) The compound enhances photosynthetic rate, stomatal conductance, and nutrient uptake at very low doses.

Concentration matters. Response curves show classic hormesis: stimulation at low concentrations, no effect or inhibition at higher doses. The optimal range is crop-specific but generally falls between 0.05-20 mg/L for foliar applications. Lettuce seems to respond to much lower concentrations than tomatoes.

Environmental and genetic factors influence response magnitude. Tolerant cucumber genotypes showed larger yield improvements than sensitive ones. (3) Season, light intensity, and nutrient status affect outcomes.

Triacontanol enhances stress tolerance, particularly to salinity and drought, by improving antioxidant enzyme activity, maintaining membrane integrity, and regulating osmotic adjustment. (3) (4) This makes it especially valuable in recirculating hydroponic systems where EC can drift upward.

Practical Guidelines

- Test on a small number of plants before scaling to full production.
- Keep application rates within published ranges. More is not better with triacontanol.
- Maintain consistent spray timing rather than irregular high-dose applications.
- Store stock solutions away from light and heat to preserve activity.
- Use analytical-grade triacontanol from reputable suppliers (minimum 90% purity).
- Combine with sound nutritional management; triacontanol is not a substitute for balanced feeding. Triacontanol is not a replacement for proper nutrition, irrigation, environmental conditions or media management.

Properly formulated and applied, triacontanol provides measurable improvements in productivity and stress tolerance across major soilless crops. The citations above offer detailed protocols and results for those wishing to implement this growth regulator in commercial or research settings.

Calcium silicate (wollastonite) in soilless crops

Silicon in media is not a magic switch. In soilless systems it can help, it can do nothing, and at the wrong rate or pH it can hurt. Calcium silicate sources such as wollastonite release plant-available Si into inert substrates and typically raise pH, which is useful in peat but potentially more risky in coir or already alkaline systems. A recent substrate study quantified this clearly: wollastonite steadily released Si for months and increased media pH about 0.5 to 1 unit depending on substrate composition (1). With that in mind, here is the evidence for tomatoes and cucumbers grown without soil, focusing only on media or root-zone applications.

Vansil CS-1, one of the most common forms of calcium silicate (wollastonite) used as an amendment in soilless crops.

Tomatoes

Two independent Brazilian groups that amended substrate with calcium silicate found quality benefits but also rate-sensitivity. In a factorial test across Si sources and doses, calcium silicate treatments improved postharvest durability and maintained physicochemical quality of fruits; the effect size depended on the source and the dose used (2). A protected-environment pot study that mixed calcium silicate into the substrate before transplanting reported reductions in gas exchange and chlorophyll at midcycle at higher rates, a warning that more is not always better (3). Earlier yield work that compared sources also detected response to silicon fertilization in tomatoes, but the magnitude varied with rate and material (4).

Cucumbers

When wollastonite was incorporated into the soilless substrate, 3 g L^{-1} increased yield by ~25% under moderate moisture restriction, with no penalty to soluble solids or fruit size. Lower doses or excessive irrigation did less (5). A separate work that applied a calcium-silicate solution into the substrate showed small gains in biomass under specific moisture regimes and no change in soluble solids, again pointing to context and dose as the deciding factors (6).

Practical takeaways for media use

1. Treat calcium silicate like a weak liming Si source. Expect a pH rise. In peat this can be helpful, in coir or high-alkalinity waters it can push you out of range (1).
2. Dose conservatively, then verify with tissue Si or leachate pH before scaling. Tomatoes show rate-sensitive physiology (3).
3. Target crops and situations with the strongest evidence. Cucumbers under moderate moisture restriction and strawberries in organic substrates show the clearest yield and quality benefits (5), (7).

Summary table — media or root-zone Si only

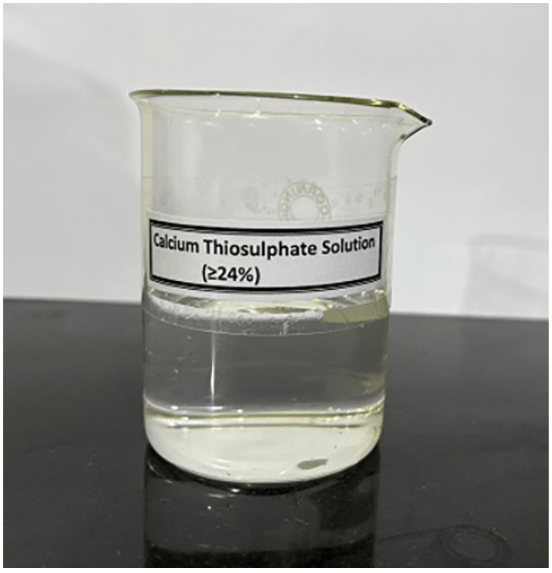
Crop	Medium and Si source	Application rate	Positive effects on yield or quality	Reported negatives	Ref
Tomato	Substrate mix, calcium silicate among Si sources	Field-equivalent 0 to 800 kg SiO_2 ha^{-1} mixed pre-plant	Improved postharvest durability and maintained physicochemical quality vs control; effect depended on dose and source	None specified at optimal rates	(2)
Tomato	Substrate, calcium silicate mixed before transplant	0, 150, 300, 450, 600 kg ha^{-1}	—	Reduced gas exchange and chlorophyll at midcycle at higher rates, indicating potential performance penalty	(3)
Tomato	Substrate, silicon sources including calcium silicate	Multiple rates	Yield responded to Si fertilization depending on source and rate	—	(4)
Cucumber	Soilless substrate, wollastonite	3 g L^{-1} of substrate under 75-85% container capacity	+24.9% yield vs untreated; fruit size and soluble solids unchanged	None noted at that rate	(5)
Cucumber	Substrate drench, calcium silicate solution	50-100 mg L^{-1} SiO_2 applied to substrate	Biomass gains under specific moisture regimes; quality unchanged	No quality gain at tested doses; response moisture-dependent	(6)
Any	Peat or coir mixes, wollastonite	~1 g L^{-1} media typical in study	Steady Si release over months supports long crops	Raises media pH by about 0.5-1 unit depending on substrate	(1)

Bottom line

Use calcium silicate where the crop and context justify it, not by default. For cucumbers and strawberries the upside on yield and quality is most consistent when Si is in the root zone. For tomatoes, treat calcium silicate as a quality tool with a narrow window and verify plant response; higher rates can backfire physiologically. If you want to try calcium silicate, mix wollastonite with your media at a rate of 3g L^{-1}, then test the effect on pH and Si in tissue.

Calcium Thiosulfate as a Nitrate-Free Calcium Source in Soilless Culture

Growers often supply calcium (Ca) with calcium nitrate, but that introduces unwanted nitrogen (N). To achieve a 0% N finish in a hydroponic or soilless system (for instance to reduce residual nitrates or alter plant metabolism), an alternative Ca source is required. One option is calcium thiosulfate (CaS_2O_3), a clear, water-soluble liquid containing about **6% Ca** and **10% thiosulfate sulfur**. Tessenderlo Kerley's CaTSR product is labeled 0-0-0-10S-6Ca (no N), and can replace $Ca(NO_3)_2$ or $CaCl_2$ in late-stage fertigation (zero-nitrogen) regimes.



Calcium thiosulfate is very soluble and can be used to prepare highly concentrated solutions

Calcium fertilizer	**Ca (%)**	**N (%)**	**Other ions / comments**
Calcium nitrate ($Ca(NO_3)_2$)	~19	~16	NO_3^- (adds N)
Calcium chloride ($CaCl_2 \cdot 2H_2O$)	~27	0	add a lot of Cl^- (1.7ppm per ppm of Ca); very soluble
Calcium sulfate ($CaSO_4 \cdot 2H_2O$)	~23	0	SO_4^{2-}; low solubility (gypsum), cannot be used to make stocks
Calcium thiosulfate (liquid)	~6	0	$S_2O_3^{2-}$; high solubility, ~10% S

Evidence and Discussion

Because research specifically on calcium thiosulfate (CaTS) is scarce, I evaluated what I *could* verify.

- A peer-reviewed article “Effects of Thiosulfate as a Sulfur Source on Plant Growth, Metabolites Accumulation

and Gene Expression in Arabidopsis and Rice" studied whether plants could use thiosulfate (instead of sulfate) in hydroponic medium. The study found that both Arabidopsis (dicot) and rice (monocot) take up thiosulfate into roots, and that at modest sulfur levels (≈300 µM) rice shows similar biomass whether S is supplied as thiosulfate or sulfate. The Arabidopsis biomass was lower when thiosulfate was used above certain concentration thresholds. This shows thiosulfate is bioavailable, though with caveats depending on species, concentration and potential toxicity or metabolic cost in dicots (1).

- Another verified study "Soil Calcium Status Unrelated to Tipburn of Romaine" (Hartz et al., 2007) compared calcium nitrate, calcium thiosulfate, and calcium chloride injections via drip in field soil on romaine lettuce. They applied 17-28 kg Ca/ha in the last 1-3 weeks before harvest and found **no significant improvement** in leaf Ca concentration of inner leaves, nor reduction of tipburn severity, regardless of Ca source (2).
- Also, "Calcium Fertigation Ineffective at Increasing Fruit Yield and Quality of Muskmelon and Honeydew Melons in California" (Johnstone et al., 2008) compared calcium from calcium nitrate, calcium thiosulfate, and calcium chloride under drip irrigation in melon. Applications of typical industry rates of Ca via CTS or CN or Cl did **not** improve fruit yield, quality, or tissue Ca concentration compared to no-Ca-fertigation control (3).

So far **no** peer-reviewed study was found that examines Ca thiosulfate in *pure hydroponic* or soilless culture to replace calcium nitrate when aiming for zero N finish (apart from its use as a sulfur source). The field soil/field drip results tend to show minimal effect of late calcium injection for inner leaves or fruit quality under the tested conditions.

With that said, studies have not revealed any negative effects from using calcium thiosulfate. My experience has shown no problems when using Ca thiosulfate as a zero-nitrogen Ca source at reasonable concentrations.

Implications

Given limited evidence, growers should be skeptical about expecting large gains in tissue calcium or disorder reduction simply by switching sources late in growth, especially under field or substrate conditions. However, using CaTSR is valid if your goal is to maintain calcium without adding nitrogen. Because it is soluble and delivers Ca in a bioavailable way (and provides thiosulfate that plants can absorb), it’s a workable tool in finish regimes where N must be zero or near zero.

The tradeoffs include:

- Possible metabolic cost in some species under certain S forms or concentrations
- If the calcium demand is high, source competition or diffusion limitations may still constrain uptake
- The very late supply may not change internal partitioning or yield, as many trials showed

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Preparing a Stock Solution and Dosing

Here is a practical plan to use CaTSR to reach **120 ppm Ca** in the final crop solution, with a **1:100 injection ratio**, without

introducing nitrogen:

1. **Determine Ca content.** CaTSR is labeled as ~6% Ca by weight (≈60 g Ca per liter if density ~1 kg/L). Confirm with product label or lab test.
2. **Stock concentration target.** To get 120 ppm in the working solution via 1:100 injection, the stock needs to be ~100× that: **12000 ppm Ca** in stock.
3. **Stock solution dilution.** Since CaTSR has ~60000 ppm Ca when pure (100%), you need ~20% of that pure product in stock to get 12000 ppm. This means uou should add ~200mL/L (~750mL/gal) of stock with the rest being distilled or RO water. This should replace your normal Ca nitrate stock.
4. **Injection.** Use an injector that can do 1% injection (38mL/gal). That gives ~120 ppm Ca.
5. **Adjustments.** If the product is more dilute or denser, revise proportionally; check electrical conductivity (EC) and pH when adding CaTSR as it may shift pH or interact with other ions.

Summary

Using calcium thiosulfate (e.g. CaTSR 0-0-0-10S-6Ca) allows growers to maintain calcium levels while eliminating added nitrogen. The dilution above (~20% product in stock, injected 1:100) yields ~120 ppm Ca. Existing studies show thiosulfate is absorbed and usable (1), but field trials using CaTS late in growth often do **not** show improvements in tissue Ca, yield, or quality when compared to controls using other Ca sources or none (2), (3). Growers should expect moderate effects at best in substrate or field systems, unless other limiting factors are addressed.

A low cost DIY oil IPM for your crops

An emulsified vegetable oil spray can smother mites and soft-bodied insects and can suppress powdery mildew if you actually coat the target. Soybean oil has the strongest evidence. Corn oil works too, and blending the two offers some advantages. In the following article I tell you how to prepare such a spray as well as some of the scientific evidence showing how it works.

Corn oil, one of the main components of this IPM spray

Why combine soybean and corn oil?

- **Fatty acid profiles differ.** Soybean oil is richer in unsaturated fatty acids (linoleic, linolenic), while corn oil contains more oleic and palmitic. That mix can change the viscosity and spreading behavior on leaves.
- **Broader efficacy.** Soybean oil has strong data against

powdery mildew, mites, and whiteflies (1) (2) (3). Corn oil has been validated in cucumber mildew trials (5). Using both hedges against variability between pests and crops.
- **Physical properties.** Mixed oils can emulsify more easily and form finer droplets than a single oil, which may improve coverage and reduce visible residues.

Why use both Tween 20 and Tween 80?

- **Hydrophilic balance.** Tween 20 (polyoxyethylene sorbitan monolaurate) is more hydrophilic, while Tween 80 (polyoxyethylene sorbitan monooleate) is more lipophilic. Together, they stabilize emulsions of mixed triglyceride oils better than either one alone.
- **Reduced creaming/separation.** A dual-Tween system forms smaller, more stable droplets that resist breaking apart. This means the concentrate stays uniform longer and the spray deposits more evenly on foliage (4).

Step 1. Prepare the concentrate

Mix in a clean container:

- **Soybean oil:** 200 mL per liter (~760 mL per US gallon)
- **Corn oil:** 200 mL per liter (~760 mL per US gallon)
- **Tween 20:** 10 mL per liter (~38 mL per gallon)
- **Tween 80:** 10 mL per liter (~38 mL per gallon)
- Fill with clean water to reach 1 L (or 1 gal).

Mix for at least 30 minutes, ensure it is uniform. Always mix well before use. This is the concentrate: **20% soybean oil, 20% corn oil, 1% Tween 20, 1% Tween 80**.

Step 2. Dilute for spraying

For foliar application:

- **Dilution rate:** Add ~20mL of concentrate per liter of water (~75 mL per US gallon of water). If pests are present you can increase the rate up to 32mL/L (~120mL/gal).
- **Note on coverage:** Coverage is critical for this spray to work as it only kills insects on contact or prevents PM by building an oil film on the leaf that prevents spore germination. Without full coverage effectiveness will drop.

This produces a **0.8% oil spray** with **0.02% Tween 20 and 0.02% Tween 80** in the final spray solution. Mix well before use.

Shelf life considerations

- **Concentrate:** A freshly prepared concentrate can stay stable for several weeks if kept sealed, cool, and out of light. Always shake well before use, since some slow separation can occur.
- **Diluted spray:** Once mixed with water, use the spray the same day. Emulsions can separate within 12-24 hours, and microbial growth in water can destabilize the mix. Discard leftovers rather than storing diluted spray.
- **Indicators of instability:** Layering, large oil droplets, or visible separation mean the emulsion is breaking, don’t spray that on plants without mixing well again.

Why it works

Soybean oil sprays at 2% suppressed powdery mildew on roses and tomatoes (1), reduced spider mites by 97-99% (2), and

deterred whiteflies (3). Corn oil added control of cucumber mildews (5). Tweens stabilize and spread the oils (4).

Bottom line

- **Concentrate:** 200 mL soybean oil + 200 mL corn oil + 10 mL Tween 20 + 10 mL Tween 80 per liter (or 760 mL + 760 mL + 38 mL + 38 mL per gallon), topped up with water.
- **Spray dilution:** 75 mL concentrate per gallon of water.
- **Final spray:** 0.8% oil, 0.02% Tween 20, 0.02% Tween 80.
- **Shelf life:** Weeks for concentrate (if stored sealed, cool, dark); hours for diluted spray.

This blended, dual-Tween foliar spray is a low-cost, evidence-backed way to add an oil-based control into hydroponic IPM programs.