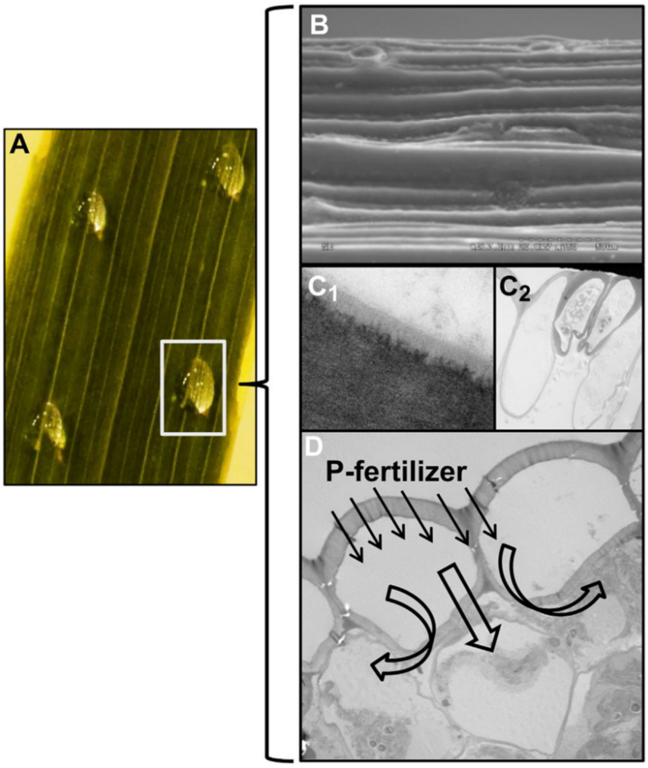
Foliar Sprays in Hydroponics: What Actually Enters the Plant?

Foliar feeding occupies a paradoxical space in hydroponic cultivation. Growers routinely spray nutrients on leaves expecting rapid correction, yet the science reveals a much narrower window of utility. The plant cuticle evolved as a barrier to prevent water loss, and this same barrier severely restricts nutrient entry. The answer is neither "foliar feeding is useless" nor "spray everything on leaves" but rather "foliar nutrition works for specific problems under constrained conditions."

The cuticle is a formidable hydrophobic barrier

The plant cuticle is a lipid-rich protective membrane that covers all aerial surfaces. It consists of three main components: cutin (a polyester of C16 and C18 hydroxy fatty acids), embedded waxes (C20 to C40 very-long-chain fatty acids), and a smaller fraction of polysaccharides that can reach up to 20% of cuticle mass (1). This structure evolved specifically to prevent water loss from leaves, making it inherently resistant to water-soluble nutrient penetration.

The critical transport barrier within the cuticle is the "limiting skin" which provides almost all resistance to penetration (1). Cuticles vary enormously across species. A foliar spray effective on lettuce may fail completely on tomato.



A comprehensive diagram illustrating the major factors affecting foliar absorption, including: P fertilizer drops on wheat leaf surface, SEM micrograph of leaf surface structure, TEM micrographs showing cuticle penetration pathways (both through cuticle and stomatal pores). Taken from this article.

Two distinct pathways exist for substances to cross the cuticle. Lipophilic compounds dissolve into the waxy matrix and diffuse across following a dissolution-diffusion model. Hydrophilic ions and polar nutrients require a completely different route through aqueous pores lined with polar functional groups (2). For most water-soluble fertilizers, this aqueous pore pathway is the only viable option.

Molecular size creates hard limits on penetration

The aqueous pores in plant cuticles impose strict size limitations on what can enter. Research using various ionic compounds has established that average pore radii range from 0.45 to 1.18 nm depending on plant species (1). This means that only very small, water-soluble compounds can squeeze through these tiny channels.

Parameter	Value	Practical Implication
Aqueous pore radii	0.45 to 1.18 nm	Only small ions penetrate efficiently
Maximum molecular weight	~800 g/mol	Large chelates must dissociate first
MW 100→500 penetration decrease	7 to 13× slower	Larger nutrients penetrate much slower

The relationship between molecular weight and penetration rate follows a clear pattern. Increasing molecular weight from 100 to 500 g/mol decreases rate constants by factors of 7 to 13 (1). The largest molecules demonstrated to pass through cuticular pores had molecular weights around 769 g/mol, establishing an approximate upper limit for ionic penetration.

For lipophilic compounds, size effects are even more pronounced. A fourfold increase in molecular weight results in a greater than 1000-fold decrease in cuticular mobility (2). This explains why small neutral molecules like urea penetrate rapidly while larger molecules move slowly.

However, the molecular weight cutoff is not absolute. Chelates can dissociate at the leaf surface, releasing free metal ions that then penetrate through aqueous pores. Iron-EDTA formulations can still deliver iron to leaf tissue even though the intact chelate is too large to pass through the cuticle.

Electrical charge determines whether nutrients stick or penetrate

The plant cuticle carries a net negative charge due to carboxyl and hydroxyl groups in the cutin matrix (2). Cations are attracted to the negatively charged surface and diffuse passively once contact is made. Anions face electrostatic repulsion and penetrate poorly until internal charge is balanced by cation entry.

Charge Type	Cuticle Interaction	Penetration Efficiency
Neutral (urea)	No interaction	Fastest penetration
Monovalent cations	Moderate attraction	Good penetration
Divalent cations	Strong attraction	Often trapped at surface
Anions	Repulsion	Poor initial penetration

This explains why urea nitrogen penetrates leaves rapidly while ionic forms of most micronutrients struggle. The charge-neutral urea molecule bypasses the electrostatic complications that slow down ionic forms (3).

The situation becomes more complex after nutrients cross the cuticle. The leaf apoplast also carries negative charges that bind cations like zinc, iron, and calcium, limiting translocation (2). As discussed previously, this means foliar micronutrients often remain localized. However, for visible deficiency symptoms, localized correction may be exactly what is needed to maintain crop quality while the root zone issue is corrected.

Surfactants improve uptake but cannot overcome fundamental limits

The primary function of surfactants in foliar applications is reducing surface tension to improve wetting and spreading. Water has a surface tension of approximately 72 mN/m, which surfactants reduce to 25 to 30 mN/m (4). This allows spray droplets to spread across hydrophobic leaf surfaces rather than beading up and rolling off.

Surfactants also directly enhance penetration through the cuticle by increasing rate constants by factors of up to 12 for ionic compounds (2).

Organosilicone surfactants can achieve surface tensions below 25 mN/m, enabling stomatal infiltration (3). This bypasses the cuticle by forcing liquid through stomatal pores. While variable and dependent on stomatal aperture, commercial agriculture uses this approach precisely because when conditions align, the payoff can be substantial.

One study on wheat found that phosphoric acid uptake reached approximately 80% when surfactants were included, compared to only 7 to 27% without surfactant (5). However, high uptake did not guarantee yield benefits. Only one of several treatments tested produced a 12% yield increase, while two treatments actually decreased yield despite similar foliar uptake rates. Yet focusing solely on final yield misses an important point: in hydroponics, visual quality, rapid symptom correction, and preventing irreversible tissue damage often matter more than marginal yield increases measured in field trials. A foliar spray that greens up symptomatic leaves within days may be economically rational even if it adds zero grams to final harvest weight.

Common misunderstandings about foliar nutrition

Many growers apply foliar sprays with expectations that don't align with the science. The key is understanding foliar nutrition as damage control rather than primary nutrient delivery.

Misunderstanding 1: High uptake guarantees benefit. Even when penetration rates appear impressive (say 80% of applied nutrients crossing into the leaf), this does not translate to plant-wide nutrition. Many nutrients remain localized to treated leaves. Calcium and manganese are particularly immobile after foliar application (2). However, localized uptake is not a failure when the goal is preventing irreversible damage to symptomatic tissue. Greening up chlorotic leaves matters for crop value even if the nutrient never reaches the roots.

Misunderstanding 2: Foliar feeding replaces root nutrition. While foliar nutrition can supplement root uptake, it cannot replace it for macronutrients. The leaf surface area simply cannot absorb the quantities of nitrogen, phosphorus, and potassium required for normal growth. Foliar sprays work best as emergency response tools for visible deficiencies while root zone issues are diagnosed and corrected. This is not a limitation but the intended use case.

Misunderstanding 3: More surfactant means better results. Surfactant concentration requires optimization. Too little provides minimal benefit, but excessive surfactant causes phytotoxicity and leaf scorch that kills the very cells needed to absorb nutrients (5). Some surfactants have even been shown to increase plant disease severity (4).

Misunderstanding 4: Biological inefficiency equals economic irrationality. Foliar sprays may be inefficient biologically but can still be economically rational. When adjusting reservoir composition requires draining tanks or deficiency symptoms threaten late-stage crop quality, a foliar spray costing a few dollars may be worthwhile even if only 10% of nutrients enter the plant. The relevant comparison is cost of application versus cost of delayed harvest or reduced quality.

Environmental conditions during application (humidity, temperature, light), plant developmental stage, and formulation chemistry all interact in complex ways (3). Relative humidity is particularly critical because penetration essentially stops once spray droplets dry on the leaf surface. Applications at 50% humidity may achieve only 1% of the penetration possible at 100% humidity (1). This does not make foliar feeding futile but rather emphasizes the importance of proper timing and environmental conditions for success.

Practical recommendations for hydroponic growers

Treat foliar sprays as emergency correction tools, not primary nutrition delivery systems. As we noted in our previous discussion, timing is critical for optimal results. Applications are best performed during afternoon after temperatures have dropped (usually after 3PM) or early morning when vapor pressure deficit is lower and stomata are more likely to be open.

Focus on small, uncharged molecules when possible. As outlined in our greener foliar spray formulation, urea for nitrogen correction provides superior penetration compared to ionic nitrogen forms. For micronutrient deficiencies, recognize that foliar-applied zinc, iron, and manganese often remain localized to treated leaves. This localization is not necessarily a failure if your goal is preventing damage on currently symptomatic tissue rather than feeding the entire plant.

Always address the root cause. Foliar applications buy time and prevent damage, but cannot substitute for proper root zone nutrition. If you find yourself making repeated foliar applications for the same deficiency, the problem lies in your reservoir composition or growing environment, not in your spray technique.

Have you tested foliar applications in your hydroponic system? What results have you observed? Share your experience in the comments below.

Nutrient problems and foliar sprays

Nutrient related issues are common in hydroponic crops. They can happen due to a large variety of issues, including pH drifting, EC drifting, lack of proper nutrient ratios, humidity issues, temperature issues and root damage. The fact that an issue is of a nutritional nature will be evident within a leaf tissue analysis, but its correction by changing the nutrient solution's composition might not be evident, since transport problems imply that a deficiency in tissue might happen for a wide variety of reasons different than the concentration in the nutrient solution being "too low" (read more here). In today's post I will talk a bit about why the quickest path to recovery might actually be to perform foliar sprays instead of only attempting to change the chemistry of the nutrient solution.

Let's first talk a bit about nutrient transport in plants. A foliar analysis might be showing you a low level of an element like K in tissue, but this does not necessarily mean that the plant doesn't have enough access to K in the nutrient solution. All we know from a foliar analysis is that K has not been able to go into the leaves, but this doesn't automatically mean that K in solution is too low. This problem can happen if the temperature of the room is too high and the relative humidity is too low – very high VPD conditions – in which calcium and magnesium will be uptaken very aggressively and the plant will be deprived of potassium significantly. You can see this in studies like this one where it is clearly shown that the concentration of potassium in tissue is proportional to VPD more aggressively than to K concentration in nutrient solution.

The real fix to a problem like the problem above would be to lower the VPD of the environment – by reducing temperature or increasing relative humidity, depending on what's wrong – but choosing to just increase the amount of K in the nutrient solution would only lead to a minor response from the plant (because that's not the problem in this case). *If the grower makes an assumption and that assumption is wrong, then significant time would have been lost in the fixing of the problem and the leaf tissue analysis will reflect very limited progress.*

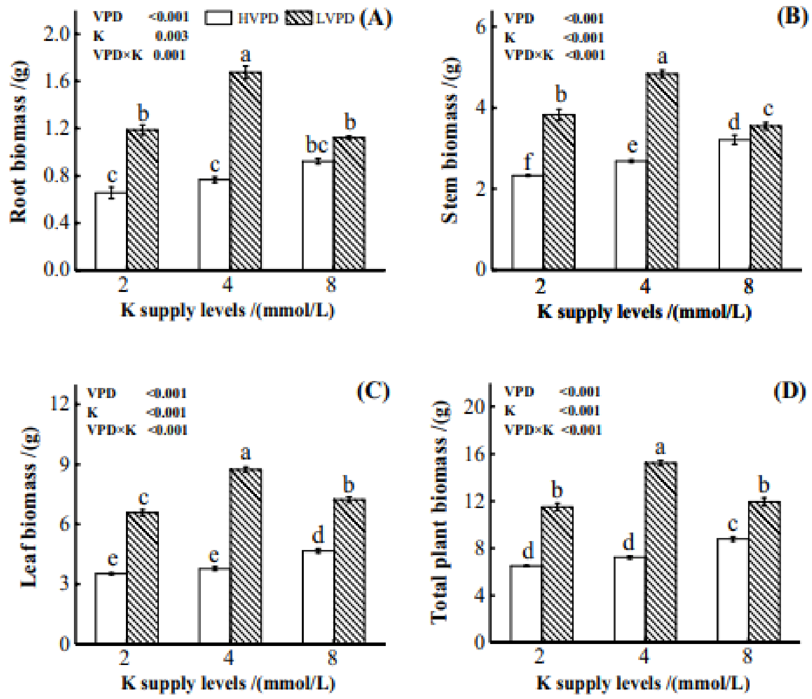


Fig. 5 Effects of vapor pressure deficit (VPD) and K supply on **a** root; **b** stem; **c** leaf; and **d** total plant biomass on day 30. Data represent the mean ± SE ($n = 5$). Different letters indicate significant differences as determined by Tukey's test ($P < 0.05$). A two-way ANOVA was performed to test the effects of VPD, K supply (K) and their interaction (VPD × K)

Image taken from this study, showing the relationship between VPD conditions and K

This is where foliar spraying comes into play. In order to "hedge our bets" in the fixing of a nutritional problem, we might want to increase the supply of the nutrient available to plant leaves by applying that nutrient to leaves directly while we figure out what is wrong with the environment or the nutrient solution. This will alleviate the issue because we will be delivering the nutrient directly to leaf tissue, regardless of what the actual root cause of the problem creating the blockage in nutrient transport is. That way, if we are wrong about the fix, we will already have made some progress in fixing the problem by delivering the nutrient that we're failing to transport where it is more strongly required.

Granted, there are a couple of caveats here. *The first is that we must have leaf tissue analysis so that we are sure about what needs to be applied (no guessing).* The second is that we still need to look into what the root cause is and solve the issue, otherwise the foliar spraying will eventually reach a limit and be unable to completely get the plants back to full health. Think of the foliar sprays as the CPR you can give your plants while the ambulance is on the way, the plants won't be able to survive from the CPR forever, but it will help them stay alive while the true solution for the problem arrives.

Table 3
Zinc and iron concentrations ($\mu g\ g^{-1}$ on dry weight basis) in different parts of two cultivars of tomato plants grown at different levels of zinc with or without foliar application of zinc sulphate

Zn concentration in nutrient solution ($\mu mol\ l^{-1}$)	Zn concentration sprayed to the leaves ($mmol\ l^{-1}$)	'Blizzard'			'Liberto'		
		Leaves	Fruit	Root	Leaves	Fruit	Root
Zinc							
0.15	0.00	11 a[a]	16 a	46 a	16 a	14 a	43 a
	0.35	56 c	25 b	63 a	75 c	23 b	41 a
	3.50	541 d	32 c	65 ab	630 d	30 c	71 b
7.70	0.00	33 b	30 c	162 c	36 b	22 b	96 c
Iron							
0.15	0.00	122 d	87 c	2333 a	111 d	74 b	1521 a
	0.35	93 b	77 b	2335 a	84 b	80 bc	2364 b
	3.50	72 a	61 a	6187 c	73 a	60 a	4660 d
7.70	0.00	97 c	85 c	3561 b	98 c	84 c	3565 c

[a] Within each column, same letter indicates no significant difference between zinc treatments (HSD at 99%).

Table taken from this study showing how effective foliar applications of Zn can be in delivering the nutrient to leaves in tomato plants

To design a foliar spray to alleviate a deficiency, first read my post about some important considerations when using this technique. Second, make sure you start with lower concentrations, to prevent further stressing plants that might already be subjected to a significant degree of stress. Third, make sure you test the foliar spray on a small group of plants so that you know what the response of the plants will be before applying to the entire crop. Under some circumstances using this method might cause additional issues, so it's important to make sure the plants can take the spray before subjecting a larger number of plants to it. When doing a foliar spray to alleviate a deficiency I suggest carrying it out only once a week initially and moving to two times per week if necessary until the root cause is fixed and the applications can be stopped.

If you are currently facing a nutrient deficiency problem and would like my help in formulating a foliar fertilizer for your specific case feel free to use the contact form or book an hour of consultation time so that we can further discuss your issue and help you fix your crop's condition.

Five important things to consider when doing foliar spraying

Foliar spraying is a true and tested way to increase yields and prevent issues in plant culture. Both soil and hydroponic growers have used foliar fertilizer applications to increase yields and prevent problems due to nutrient deficiencies during the past 50 years. However there is a lot of mystery and confusion surrounding foliar fertilizer applications, reason why this technique is often applied incorrectly or sub-optimally. Today I want to talk about 5 key pieces of information to consider when doing foliar fertilization so that you can be more successful when applying it to improve your crop results and reduce deficiency problems. If you want to learn more about these factors I suggest you read the following reviews on foliar feeding (here, here and here). Second table in this post was taken from this study on wheat.

Foliar fertilization is not root fertilization. A usual problem when doing foliar fertilization is to think that the same products can be used for leaves and roots. When you want to increase your crop yields using foliar fertilization you should definitely not use the same products and concentrations you use for soil. There are for example some chemical substances that you would never want to apply to the roots that have actually shown to give better outcomes in leaves. A good example is calcium chloride which is a huge mistake in root fertilizers but a great choice when doing foliar fertilization.

Foliar fertilizers should generally be much more concentrated. When people apply foliar fertilization they usually apply much lower concentrations because they are afraid of burning leaves. Although this can certainly happen if the foliar fertilizer is badly designed research has shown that the best results are obtained with much higher concentrations than what you generally use for the roots. For example when you apply an iron foliar fertilization regime you generally use a concentration of 500-1200 ppm of Fe while in root applications you only very rarely go beyond 4-5 (most commonly 1-3 ppm). Usually concentrations in foliar fertilizers will be much higher and if the fertilizer is correctly designed this will give much better results. The graph below (taken from the first review linked above), shows some of the most commonly used fertilizer concentrations.

Surfactants are very important (don’t use dish washing soap!). Leaf coverage is very important in foliar applications because you want the fertilizer to be evenly spread across the entire leaf not “clumped” into drops due to surface tension. Many people have trouble with nutrient burn due to bad fertilizer design that causes inadequate leaf coverage. However all surfactants are not created equal and ionic fertilizers are very undesirable for this task due to their interaction with leaf tissue and fertilizers. Due to this reason you should NOT use something like dish washer liquid soap but a proper non-ionic surfactant like a polysorbate. The surfactant will be a very important part of your foliar fertilizer formulation.

Timing is also critical. The time when you do your foliar sprays applications is also very important for optimal results. In general you want the leaf stomata to be open and the vapor pressure deficit to be lower so the best time to do foliar spraying is usually during the afternoon after temperatures have dropped significantly. For most time zones this usually means sometime after 3PM. Doing foliar applications sooner can lead to much larger stress due to a higher vapor pressure deficit – risking burns as well – while doing it later leads to less efficient absorption due to the stomata being closed. If applying the spray at this time is not possible then early morning often works as well. Make sure you measure your daily temperature/humidity fluctuations to ensure you don’t do foliar sprays at a high VPD.

Couple adequate additives for yield increases. Research has shown that while nutrient foliar spraying can enhance yields significantly under sub-optimal root feeding conditions if the root concentrations are already optimal – as in a well managed hydroponic crop – it is hard for simple nutrient foliar spraying to provide a lot of benefit. However there are several biostimulants that are poorly absorbed through the root zone that can give you much better results when used as foliar sprays. Additives like salicylic acid and triacontanol can make sure that your nutrient foliar spray gives you maximum additional benefits.

As you can see there is a lot to the design of an adequate foliar spray. You must consider that the substances you use need to be fit to the purpose – not necessarily the same as for root applications! – and that your concentrations, surfactants, additives and application times are adequate. Now that you are aware of these factors you should take them into account when designing your next round of foliar spraying for your crops.