A Recipe for Hydroponic Success

Providing all of the essential elements in the right quantity and the right proportion to each other can seem like a daunting task to even the most mathematically gifted growers.

by **NEIL S. MATTSON & CARI PETERS**

Among the more challenging questions for growers beginning hydroponic production is how to design the crop's fertilizer program. Plants require 14 essential elements in the root zone, including the macronutrients (needed in relatively large quantities) of nitrogen, phosphorus, potassium, sulfur, calcium and magnesium; and the micronutrients (needed in relatively small quantities) of iron, manganese, zinc, boron, copper, molybdenum, chloride and nickel. All of these nutrients must be supplied by the hydroponic nutrient solution, although chloride and nickel aren't included in most recipes, as they're available in sufficient quantities as impurities with the fertilizer.

Fortunately, plants have adapted to growing at a wide range of nutrient concentrations. From a practical standpoint, this means that many different nutrient solution recipes can be used successfully to grow a hydroponic crop. With so many different recipes to choose from, where do you begin and how should you make changes and improvements from there?

Key factors when selecting fertilizers

In hydroponics, it's absolutely essential to begin with a laboratory analysis of your water. The three main things to note are the alkalinity, the electrical conductivity (EC) and the concentration specific elements. Alkalinity is a measure of water's ability to neutralize acid. Alkalinity is usually reported in terms of ppm of calcium carbonate equivalents ($CaCO_3$). Alkalinity values may range from near 0 (in very pure or reverse osmosis-treated water) to more than 300 ppm $CaCO_3$. The greater your water's alkalinity, the more the pH will tend to rise in your nutrient solution.

Water source alkalinity is a much more important number to look at than its pH. The pH is simply a one-time snapshot of how acidic or basic your water is; alkalinity is a measure of its long lasting pH effect. Once you know your water alkalinity, you can work with your local extension educator, fertilizer supplier or testing laboratory to select an appropriate fertilizer strategy. Depending on your alkalinity, you may need to choose a formulation with a greater proportion of acidic nitrogen forms (ammonium or urea) or add acid to neutralize the alkalinity and counter the pH rise.

Next, consider the EC of your water source. EC is a measure of the total dissolved salts, including both essential elements and unwanted contaminants (such as sodium). Therefore, EC is a rough measure of water source purity. Unfortunately, EC gets reported using several different related units, however, it's easy to convert between them: 1 mS/m = 1 mS/cm = 1 mmhos/cm = 1000 µmhos/cm = 1000 µS/cm. Knowing water source EC will help you determine whether to use an open or closed irrigation system. In closed hydroponic systems, the irrigation water is captured and reused, whereas in open systems, it's not. EC should ideally be less than 0.25 mS/cm for closed systems.

Many hydroponic growers have found it necessary to filter source water, often using reverse osmosis, so that it's pure enough for closed hydroponic systems. The only way to counter salt build-up in closed systems is to "bleed" the reservoir—that is, purposely drain off some fraction of the nutrient solution and replace this with fresh water. In open systems, the build-up of salts can be managed by applying excess water to leach out soluble salts. Therefore, source water EC can be higher than in closed systems—ideally less than 1.0 dS/cm.

The laboratory water analysis will also tell you which specific essential elements and contaminants are in your water. The concentration of essential elements should be taken into account when preparing your fertilizer recipe. Often linked with your water alkalinity are considerable levels of Ca, Mg and S in the water. Be sure to look and see if your water contains these important secondary nutrients and at what concentration, then be prepared to supply these nutrients through your fertilizer program if not available in sufficient quantities for your crop's recipe. Sodium and chloride are common contaminants in some waters; ideally these should be less than 50 and 70 ppm, respectively. This can help you determine the need to purify your water, leach or bleed more frequently, as well as to avoid these contaminants in the fertilizer.

Once you know your water source quality you can begin to plan a fertilizer strategy specific to your crop. Plant fertilizer concentration needs vary depending on the crop grown, the crop growth stage and environmental conditions. However, for a new grower, a good starting point is to simply develop one recipe that works decently well for a range of crop growth stages and conditions. Later, you can work on honing the recipe, optimizing it for different growth stages or based on your current growing conditions.

Recipes for lettuce, herbs and leafy greens

For vegetative crops, most nutrient-solution recipes don't adjust the ratio of nutrients while they grow; whereas, in fruiting crops the ratio may be adjusted to alter the shift between vegetative and reproductive growth. At Cornell's Controlled Environment Agriculture group, for many years we've successfully used a modified Sonneveld's recipe for growing lettuce >>>

Table 1. Three hydroponic nutrient solution recipes to prepare 100 gal. of fertilizer suitable for hydroponic production of lettuce, herbs and leafy greens. If preparing to dilute in a 100-gal. reservoir, all the components within a recipe can be mixed into the water. If using stock tanks (i.e., a 100X concentration), then the calculations represent the amount to use per 1 gal. of stock. Where indicated, the Tank A and Tank B components MUST be prepared separately so a precipitate does not occur. If using stocks, dilute using 1:100 injector(s) (two injectors connected in series for Tank A and Tank B mixes). This will make 100 gal. of dilute fertilizer.

Jack's Hydro-FeEd (16-4-17)	
This is a 1-bag solution; use 355 g in 100 gal. water (dilute) or for each 1 gal. in a stock tank (using a 1:100 injector)	
Jack's Hydroponic (5-12-26) + Calcium nitrate	
Tank A	**Tank B**
284 g Calcium nitrate (15-0-0)	284 g 5-12-26
Modified Sonneveld's solution for lettuce	
Tank A	**Tank B**
184.0 g $Ca(NO_3)_2 \cdot 3H_2O$	51.5 g KH_2PO_4
14.4 g NH_4NO_3	93.1 g $MgSO_4 \cdot 7H_2O$
167.3 g KNO_3	*0.290g $MnSO_4 \cdot H_2O$
*3.8 g 10% Iron-DTPA Sprint 330 or Sequestrene 330	*0.352g H_3BO_3
	*0.023g $Na_2MoO_4 \cdot 2H_2O$
	*0.217g $ZnSO_4 \cdot 7H_2O$
	*0.035g $CuSO_4 \cdot 5H_2O$

*A precise scale is needed to weigh the micronutrients

Figure 1. Stock tanks at a commercial hydroponic greenhouse.

and other leafy greens (spinach, pak-choi) (Table 1). You will notice that this is a made-from-scratch recipe that requires mixing of several individual compounds. Large commercial operations often follow the made-from-scratch method because of the ability to adjust individual compounds and because it can be more cost effective to purchase the individual compounds in bulk.

This is a good time to point out that most hydroponic recipes call for the use of two or three stock tanks (Figure 1). This is necessary to avoid a nasty precipitate or sludge that will occur when specific nutrients are mixed in the concentrated form. In particular, calcium can combine with phosphates and sulfates to form insoluble precipitates. If you're not mixing these formulas in concentrated stock solution and rather mixing in a dilute or "ready-to-use" form, you can mix these prescribed amounts into one reservoir containing the final water volume. In this case follow a stepwise fashion, where each component is added individually and goes into a true solution before you add the next nutrient. This is where it's very important to pick quality nutrients that are very pure and 100% water-soluble.

The made-from-scratch method can be difficult for new or smaller hydroponic growers to manage. One commonly used alternative is a two-bag approach using Jack's Hydroponic (5-12-26) and calcium nitrate (Table 2). In this method, Tank B contains 5-12-26 pre-blended formula mixed at a rate to deliver approximately 50 to 100 ppm N. Tank A contains calcium nitrate at 100 to 150 ppm N and can also be used to add in some useful crop-specific boosters, such as potassium nitrate or individual micronutrient chelates such as iron-EDTA, DTPA or EDDHA. If acid is required to neutralize source water alkalinity, this may be added to Tank B (the tank without Calcium nitrate) or some operations use a separate tank for acid.

A relatively new one-bag alternative is Jack's Hydro-FeED (16-4-17). This formula is specifically designed to be used as a one-bag formula to deliver a complete nutrient solution to hydroponic and aeroponically grown crops. It was developed specifically for leafy green and herb growers, but has also seen much success as the main grower formula for tomato, cucumber and pepper crops. What's unique about this formula is its potentially neutral effect on solution pH, as well as its buffered micronutrient package that also includes the essential blend of iron chelates from EDTA, EDDHA and DPTA. This formula works well for water types with an alkalinity in the range of 40 ppm to 200 ppm N.

As you grow your skills mixing fertilizers and observing impacts on plant growth, you may be ready to begin adjusting your fertilizer program. For example, you may take into account the slightly lower fertilizer needs during propagation or the specific fertilizer needs of different

Table 2. Comparison of the nutrients (in ppm) supplied by the three different recipes for lettuce, herbs and leafy greens.

	Jack's Hydro-FeED (16-4-17)	Jack's Hydroponic (5-12-26) + Calcium nitrate	Modified Sonneveld's solution
Nitrogen (N)	150	150	150
Phosphorus (P)	16	39	31
Potassium (K)	132	162	210
Calcium (Ca)	38	139	90
Magnesium (Mg)	14	47	24
Iron (Fe)	2.1	2.3	1.0
Manganese (Mn)	0.47	0.38	0.25
Zinc (Zn)	0.49	0.11	0.13
Boron (B)	0.21	0.38	0.16
Copper (Cu)	0.131	0.113	0.023
Molydenum (Mo)	0.075	0.075	0.024

Table 4. Two hydroponic nutrient solution recipes to prepare 100 gal. of fertilizer suitable for hydroponic production of tomatoes, cucumbers and peppers.

Jack's Hydroponic (5-12-26) + Calcium nitrate	
Tank A	**Tank B**
360 g Calcium nitrate (15-0-0)	360 g 5-12-26
UA CEAC Recipe*	
Tank A	**Tank B**
347.8 g $Ca(NO_3)_2{\cdot}3H_2O$	64.9 g KH_2PO_4
152.5 g KNO_3	184.3 g $MgSO_4{\cdot}7H_20$
*7.6 g 10% Iron-DTPA Sprint 330 or Sequestrene 330	114.7 g K_2SO_4
	*0.641g $MnSO_4{\cdot}H_2O$
	*0.606g H_3BO_3
	*0.048g $Na_2MoO_4{\cdot}2H_2O$
	*0.549g $ZnSO_4{\cdot}7H_2O$
	*0.074g $CuSO_4{\cdot}5H_2O$

*A precise scale is needed to weigh the micronutrients
Adapted from University of Arizona, Controlled Environment Agriculture Center, http://tinyurl.com/ljlj785/

Table 3. Target nitrogen feed rates (in ppm N) for several hydroponic crops.

Type	Propagation	Production
Buttercrunch/Boston Bibb	125	150
Romaine, Red and Green leaf	125	150
Basil	125	175
Culinary Herbs	125	150
Cole Crops	125	175
Garlic and Scallions	125	150
Tomatoes	125	200
Peppers	125	150
Cucumber	125	175
Heavy Feeders cabbage, kale, spinach, Swiss chard, mustard greens, mizuna, escarole	125	175 - 200
Light Feeder Lettuce arugula, watercress, spring mix	125	125 - 150

* Adapted from data collected at J.R.Peters Laboratory and Smithers Oasis Inc. 2012-2013

Table 5. Comparison of the nutrients (in ppm) supplied by the three different recipes for lettuce, herbs and leafy greens.

	Jack's Hydroponic (5-12-26) + Calcium nitrate	UA CEAC Recipe
Nitrogen (N)	190	189
Phosphorus (P)	50	39
Potassium (K)	205	341
Calcium (Ca)	176	170
Magnesium (Mg)	60	48
Iron (Fe)	2.85	2.00
Manganese (Mn)	0.48	0.55
Zinc (Zn)	0.14	0.33
Boron (B)	0.48	0.28
Copper (Cu)	0.14	0.05
Molydenum (Mo)	0.10	0.05

crops. For example, a target of 150 ppm N works well for head and leaf lettuce during the main production stage; whereas a target of 175 to 200 ppm N is more appropriate for kale, Swiss chard and mustard greens, which tend to be slightly heavier feeders (Table 3). During the seedling propagation stage a somewhat lower fertilizer target of 125 ppm N works well for both these categories.

Below: Tomatoes soon after transplanting on rockwool slabs, still in the vegetative phase.
Right: Tomatoes in the mature fruiting stage.

Recipes for tomato and other fruiting crops

Fruiting crops tend to have higher nutrient demands than leafy greens. Besides simply bumping up the nitrogen, it's important to increase the potassium, calcium and magnesium as well. A single fertilizer recipe has worked well for growing tomatoes, cucumbers and peppers at the University of Arizona Controlled Agriculture Center greenhouse (Table 4). A similar recipe following the two-bag approach and a nutrient comparison is noted in Tables 4 and 5.

For tomatoes, commercial operations often adjust the nutrient solution recipe according to the crop growth stage. The strategy is typically to supply more nitrogen, calcium and magnesium at first to promote good plant structure and vegetative growth (Table 6). Then about six weeks after transplanting the tomato seedling, nitrogen is reduced, but potassium is increased, to promote the transition between vegetative growth and flowering and fruit set. Finally, the recipe may be adjusted again to balance vegetative and reproductive growth as the plant continues to grow and set fruit.

Honing your fertilizer recipe

Whether you're a beginner or an old pro, it's important to continually monitor your nutrient solution. Daily in-house testing of the nutrient solution pH and EC followed up by periodic full nutrient testing in a laboratory will give you a good peace of mind that you're providing nutrients in the correct quantity for the plant and the proper pH. Establishing a baseline concentration of nutrients in your reservoir through consistent testing of the solution will greatly help you determine how to make changes in the future.

To further hone your fertilizer recipes, periodic tissue sampling is a must. This lets you determine the exact nutritional status of your plant, allowing you to determine how the nutrients you apply are absorbed into, stored and redistributed in the plant. Monitoring the change in nutrient concentration over time with periodic sampling is one of the best methods of evaluating if you're providing the right nutrients to your plant, matching its growth stage and growing conditions.

Understanding nutrient mobility relationships within a plant will greatly enhance how you interpret and use the data generated by a tissue analysis. Young leaves tend to show higher levels of the mobile nutrients (nitrogen and potassium) and lower levels of immobile nutrients (calcium, iron and manganese). Therefore, samples taken from young leaves can be most useful to diagnose calcium or micronutrient deficiencies. If no particular problem is suspected, testing laboratories typically recommend taking samples from recently matured leaves as a decent representation of what's happening to both new and old growth. Take time to evaluate your records of fertilizer inputs, light and temperature conditions, and EC/pH balance. This may allow you to come to a better understanding of why and how your actions can influence the nutrient balance in solution and in the plant's leaves.

Preparing hydroponic fertilizer solutions doesn't have to be a daunting task. Start with one recipe that makes sense for your crop. Monitor early, monitor often and as your comfort level grows, you may begin to modify the recipe to optimize crop growth. Who knows—you might find that preparing fertilizer recipes becomes as enjoyable to you as following grandma's chocolate chip cookie recipe. IG

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Table 6. Recipe for tomatoes in winter according to crop growth stage (units are ppm).

	Weeks 0-6 Higher N, Ca and Mg for vegetative growth	Weeks 6-12 Lower N, higher K for reproductive growth	Week 12+ Maintain balance of vegetative / reproductive growth
Nitrogen (N)	224	189	189
Phosphorus (P)	47	47	39
Potassium (K)	281	351	341
Calcium (Ca)	212	190	170
Magnesium (Mg)	65	60	48
Iron (Fe)	2.00	2.00	2.00
Manganese (Mn)	0.55	0.55	0.55
Zinc (Zn)	0.33	0.33	0.33
Boron (B)	0.28	0.28	0.28
Copper (Cu)	0.05	0.05	0.05
Molydenum (Mo)	0.05	0.05	0.05

Source: Sunco, Ltd., and University of Arizona, Controlled Environment Agriculture Center, http://tinyurl.com/ljlj785/