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Foliar-Applied Micronutrients in Aquaponics: A Guide to Use and Sourcing[1]

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Introduction

Aquaponics is an emerging type of agricultural production system combining two production systems: aquaculture (fish farming) with hydroponic fruit, vegetable, or herb production. One unique challenge in aquaponics is maintaining water pH at values that are suitable for all the organisms in the system. The ideal water pH for hydroponic plants is 5.5–6.5, while the ideal pH for fish and the accompanying biofilter system—discussed in more detail later—is between 7.0 and 9.0 (Tyson 2007). Plants may experience deficiency of some micronutrients at pH greater than 6.5 because many micronutrients form compounds that do not dissolve in water at these pH levels. Biofilter bacteria are responsible for changing ammonia (NH_3), which is quite toxic to fish, to relatively harmless nitrate (NO_3^-). These bacteria can survive at the 5.5–6.5 pH range, but do not convert ammonia to nitrate as quickly, putting the fish at risk of suffering ammonia toxicity.

This publication reviews the special aspects of water chemistry involved in aquaponics, especially pH, and how water chemistry contributes to maintaining sufficient crop micronutrient levels. It also summarizes the different sources of micronutrients and their potential suitability for aquaponics systems.

This information should assist growers in evaluating products appropriate for their own systems, even in the face of a constantly changing array of product options. Both organic-compliant micronutrient sources (USDA 2002) and conventional micronutrient sources will be discussed.

Individuals interested in organic production should be aware that the USDA National Organic Program final rule does not have a standard for greenhouse production, hydroponics, or aquaculture. Therefore, aquaponic fish cannot be labeled and sold as "certified organic" (Diver 2006). However, hydroponic produce may be sold as certified organic if it meets the organic requirements, and fish can be marketed as "naturally grown" or in similar green-label categories. For more information on certified organic production, visit "Introduction to Organic Crop Production" at http://edis.ifas.ufl.edu/CV118 and extension's "Organic System Plan Overview" at http://www.extension.org/article/20975.

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First Considerations with Micronutrients: pH

One of aquaponics' top management priorities is the maintenance of correct water chemistry and nutrient balance. Hydroponics typically operates at a pH between 5.5 and 6.5 because several nutrients, including iron (Fe), copper (Cu), zinc (Zn), boron (B), and manganese (Mn), become unavailable at a higher pH (Timmons and Ebeling 2002; Tyson 2007). However, both fish and biofilter bacteria perform best at a pH of 7.0 or above. Biofilter bacteria are required for fish culture because they convert the ammonia (NH_3) in fish waste, which is toxic to fish, into relatively harmless nitrate (NO_3^-). Sizing of biofilters varies depending on stocking rate, type of substrate used for the biofilter, and amount of NH_4^+ that is removed by the hydroponic plants. In the case of tilapia, the NH_3 concentration must be kept below 0.1 mg/L (0.1 ppm) by the combined NH_3 removal of the biofilter and hydroponic plants (El-Shafai et al. 2004). Although not fatal, tilapia growth is slowed at or above this level.

Tyson (2007) proposed a solution to this dilemma by maintaining pH between 7.0 and 8.0 for intensively managed systems to increase nitrification, and by applying foliar nutrients to compensate for the low availability of some nutrients in this pH range. The amount of each nutrient to use in a foliar application on aquaponic plants has not been determined and would probably be different from system to system. Therefore, the individual growers would need to determine the appropriate amounts of micronutrients for foliar application.

Correct pH is essential to the healthy functioning of an aquaponic system. Therefore, growers should check their system's pH daily, either with an electronic pH meter or with a test strip (J. Rakocy and R. Tyson, pers. comm.).

When the pH must be adjusted, growers are limited to acids and bases that are nontoxic to both fish and plants and pose little or no risk of accumulation. For example, calcium hydroxide (CaOH) and potassium hydroxide (KOH) are good choices for raising pH, since Ca (calcium) and K (potassium) are nutrients required by both plants and fish. The tilapia and produce aquaponics system at the University of the Virgin Islands maintains pH by alternating between adding CaOH and KOH (Diver 2006). Other strong bases, such as sodium hydroxide (NaOH), would maintain correct pH but would be poor choices for aquaponics because neither plants nor fish take up sodium (Na) in any appreciable amount, so it can easily accumulate in the water to toxic levels.

Phosphoric acid, or H_3PO_4, is commonly used in aquaponics and aquaculture to adjust pH downward (R. Tyson, pers. comm.). Other suitable materials for adjusting pH may be found by consulting books or periodicals on aquaponics, or by communicating with other aquaponic growers. The National Sustainable Agriculture Information Service's (ATTRA) publication *Aquaculture Enterprises: Considerations and Strategies* (Gegner 2006) has a list of both written references and aquaponic growers' associations in its resources section.

Organic producers must also consider whether acids, bases, and nutrients are allowable under the USDA National Organic Program final rule. Aquaponics constitutes a gray area under the organic regulations because neither aquaculture nor hydroponic produce is specifically addressed in the standards. For example, CaOH, KOH, and H_3PO_4 are all allowable substances under the organic standards for various situations, but not to adjust pH. In this case, it is best for growers to consult with their certifying agencies to find appropriate acids and bases for organic hydroponic produce. Fish cannot be labeled as "certified organic" under any circumstances.

Different Aquaponics Systems Have Different Micronutrient Needs

There are many hydroponic system types that can be modified to work with aquaponics; reciprocating and constant-flow systems are used most often. A reciprocating hydroponics system is one in which the hydroponic media are alternately flooded and then drained on a regular basis, usually with the plant roots in some sort of granular or fibrous media (such as sand, vermiculite, perlite, or coconut husk fiber). A constant-flow system is one in which the roots are always immersed in the nutrient solution, which flows at a constant rate 24 hours a day. These systems can use some kind of solid soilless media, but the roots can also hang freely in the solution. Examples include the raft and nutrient film systems (where the plants are positioned in floating foam or cork rafts and their roots are submerged in the flowing solution) and the trickling bed system (where plants grow in a solid soilless media with solution trickled through it) methods.

Constant-flow systems have a distinct advantage in aquaponics, where micronutrient concentration is reduced by a high pH (Tyson 2007, Tyson et al. 2008). In soil or reciprocating hydroponic systems, the water and nutrients nearest the roots are quickly taken up by the plant. Movement of more water and nutrients into the zone immediately around the root is slowed by the soil or media, leading to a zone or "halo" of nutrient depletion around the root. This effect means a higher overall nutrient concentration is needed to avoid unacceptably low nutrient levels immediately around the roots.

If the solution is constantly in motion, however, depleted zones do not usually occur, and more dilute solutions will fulfill the plants' requirements. Therefore, nutrients with low solubility at high pH (such as Fe and Mn) may have fewer deficiency problems in constant-circulation systems than in reciprocating systems. However, growers should carefully monitor for low nutrient levels.

The *Florida Greenhouse Vegetable Production Handbook* contains written descriptions of nutrient deficiency symptoms (http://edis.ifas.ufl.edu/CV265). If nutrient deficiencies are suspected, tissue testing may be performed to determine the deficient nutrient and the rate of amendment that would eliminate the problem.

Finally, some drift or dripping of foliar applications into the aquaponic solution should be expected. While the amount of foliar nutrient amendment that enters the growth solution during any given application is likely to be small, an element not used in high amounts by plants or fish (such as Na) can accumulate to toxic levels over a period of time with repeated applications. Growers should be able to anticipate the effects of any possible additions to their systems and choose amendments that contain few or no ingredients capable of accumulating to toxic levels for either fish or plants.

Sources of Micronutrients

The most widely used sources of micronutrients in agriculture are mined inorganic minerals and synthetic chelates. Chelate comes from the Greek term for "claw"; chelates are molecules that, when dissolved in water, can "grab" onto positively charged ions, many of which are plant micronutrients (such as iron [Fe^{2+} and Fe^{3+}], copper [Cu^{2+}], manganese [Mn^{2+}], etc.). Chelated micronutrients are still available to plants and prevented from binding with other molecules that would cause them to become unavailable. Some large, naturally occurring chelate molecules are present in lignin sulfonates, soil organic matter, and compost teas. These are advantageous to organic producers because, being naturally occurring, they are permissible for organic systems. Synthetic chelates include compounds such as EDTA (ethylenediaminetetraacetic acid), EDDA (ethylenediaminediacetic acid), and others.

In general, synthetic chelates and inorganic minerals are the most appropriate sources of micronutrients for aquaponics because they allow the amount of each nutrient to be controlled independently. By contrast, aquatic plant extracts and other products derived from biological sources will provide a variety of micronutrients and may not contain them in the correct ratio for an individual aquaponic system. For example, by the time a sufficient amount of one of these nutrient sources is added to provide all the Fe necessary for the system, an excess of Cu or Na may also have been added. Aquaponicists must achieve a balance between avoiding nutrient deficiencies and preventing nutrient excesses. Unfortunately, biologically derived products do not lend themselves well to this type of system.

In certified organic systems, allowable sources of micronutrients include synthetic sulfates, carbonates, oxides, or silicates of Zn, Cu, Fe, Mn, molybdenum (Mo), selenium (Se), and cobalt (Co) as long as a micronutrient deficiency is documented (see below: "Micronutrient Monitoring"). Certified organic growers should check with their certifiers before using these micronutrient supplements since the use of mineral micronutrients in hydroponic produce is a gray area in the organic standards. Table 1 provides more information on major micronutrient sources.

Micronutrient Monitoring

Overall nutrient levels will vary in each aquaponic system depending on fish stocking rate, feed and fertilizer inputs, type and amount of plants grown, etc. The tendency of each nutrient to accumulate or become deficient will also vary from system to system. For example, Fe is commonly deficient, and Zn accumulates in some systems but not in others (Timmons and Ebeling 2002). Therefore, aquaponic growers should become acquainted with the tendencies of their own systems by testing periodically.

While test kits are available for many aquaculture water quality parameter—such as dissolved oxygen, ammonia-nitrogen, and pH—reliable testing for micronutrients is more difficult. The best option is to submit samples to a laboratory that can analyze them using an ICP (internally coupled plasma) spectrometer (J. Rakocy, agricultural experimental station director at the University of the Virgin Islands, pers. comm.). For example, during the first year of operation at the University of the Virgin Islands system, operators took a water sample each month and stored it until the end of the year, at which point all 12 were submitted to a lab for micronutrient testing. A year's worth of monthly samples gives a good general idea of any nutrient accumulation or deficiency trends, and as long as general good practices are followed (such as avoiding the addition of Na to the system), toxic accumulations of micronutrients are not likely to occur. Contact the lab prior to collecting samples; they may need to be refrigerated and/or have acid added for storage.

The University of Florida offers a water testing service for agricultural and domestic use. The test results include Ca, Mg, Na, Cl, Fe, and Mn content, which are useful to aquaponic growers. It may be possible to request testing for other trace elements, such as Zn, by special order. While the results are useful, this test is oriented toward irrigation or home use rather than aquaponics and will not provide any clarifying information appropriate to aquaponics, such as whether the results are "high" or "low." Thus, the growers should either be familiar with the desired nutrient ranges for their fish and plant species, or they should review the results with an Extension agent who is familiar with appropriate nutrient levels for aquaculture and/or hydroponics.

The UF/IFAS Analytical Services Laboratories Web site (http://soilslab.ifas.ufl.edu/ESTL%20Tests.asp) offers other useful services, such as nutrient analysis of leaf tissues. It can be helpful to call the lab before sending in the samples to explain their purpose and to ensure that the results are reported in an appropriate manner for aquaponics. Growers can also locate labs in their area that can perform these tests by searching for "water testing" or "environmental testing" online, although labs can vary in quality and, unlike the university-run lab, UF/IFAS cannot vouch for their accuracy.

How the results of the test are interpreted will depend on the individual grower's plant crop and fish species. For example, whether 5 ppm Fe is too much, too little, or just right will depend on what is being grown. UF/IFAS has recommended nutrient levels for hydroponic solutions for tomatoes, cucumbers, and leafy greens in the University of Florida's *Greenhouse Vegetable Production Handbook* (http://edis.ifas.ufl.edu/CV265). Nutrient toxicity levels for fish can be determined by consulting with an aquaculture specialist, such as a consultant or Extension agent, familiar with the species and the sourcewater quality in the area.

Conclusion

Aquaponics enterprises in the United States are still few in number; two of the best examples of successful aquaponics businesses are S & S Aqua Farm in Missouri (http://www.jaggartech.com/snsaqua) and Bioshelters in Massachusetts (http://bioshelters.com). The University of the Virgin Islands has a long-running demonstration aquaponics system producing about 20,000 lbs. of tilapia annually, and various vegetables that are sold commercially (Rakocy et al. 1997). These systems are commercially successful because they can use fewer resources and net higher profits per square foot of growing space than either system alone.

Various individuals have experimented with aquaponics periodically throughout the twentieth century; however, there was little or no market viability until new innovations became available in the 1980s (Diver 2006). Therefore, aquaponics is still a new type of agriculture, and some aspects are not well understood. Additionally, many different types of systems exist. It is difficult to make specific recommendations for optimal system performance at this time. Most successful aquaponic growers have arrived at their present system configurations with at least some trial and error.

Understanding water chemistry and regularly monitoring one's system can prevent unpleasant surprises both during the learning curve and in normal operation. When considering micronutrient applications, it is important for growers to keep in mind the possibility of accumulation of toxic levels of any element that is present in excess of the amount needed by the fish and plants, and that is soluble at high pH. Both Na and general salinity meet this description and should be monitored regularly with test strips or electronic meters. Organic growers should also confirm their system plans, including micronutrient management plans, with their certifying agencies *prior* to use.

Additional Resources

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Table 1. Micronutrient sources

Material	Source/ingredients	Mode of use	Notes
Mineral sources–$CuSO_4$, $FeSO_4$, etc.	Mined rocks, usually processed for purity	Ready-to-use liquid formulas or dry formulas that must be mixed prior to use	Be sure to test and document a nutrient need prior to contacting certifying agency. Can affect pH; be prepared to adjust pH when using. Chlorides should be avoided because chlorine is toxic to both fish and plants in low amounts (C. Ohs, pers. comm.) If nitrates are added, they should be accounted for in the N budget. Neither chlorides nor nitrates are permissible under organic regulations.
Synthetic chelates–EDTA, EDDA, EDDHA, etc.	Synthetic materials that keep nutrients soluble in high-pH water	Ready-to-use liquid formulas or dry formulas that must be mixed prior to use	Not appropriate for organic systems. EDDHA is the best chelate for iron at pH greater than 7.0 (Argo and Fisher 2008)
Aquatic plant extracts	Commercially prepared "teas" of various plants; may contain micronutrients and other compounds	Liquid	Often have a base such as KOH or NaOH added to increase extraction. Take these additives into account. For example, KOH can be considered a K supplement as well, and products containing NaOH should be avoided.
Humic acids	Two sources: commercially prepared "teas" of high-organic-matter materials such as compost and soil organic matter, or derived from coal and/or sewage sludge (Sanjay et al. 1996)	Usually liquid	Approved for organic systems; however, some growers may wish to check with supplier to ensure that the humic acids are derived from compost rather than from coal.
Lignin sulfonates	A component of wood, "the glue that holds tree rings together" (TranSafety, Inc. 1998); commercial preps usually derived from paper processing	Usually liquid	Approved for organic systems.
Seaweed preparations	Commercially prepared "teas" from seaweed	Usually liquid	Approved for organic systems. However, these tend to be high in salts, making them inappropriate for recirculating aquaponic systems.

Table 1. Micronutrient sources

Material	Source/ingredients	Mode of use	Notes
Fish preparations, such as fish emulsion	Processed fish	Dry (fish meal) or liquid (fish emulsion)	Approved for organic systems. However, high N content compared to micronutrients can easily foul water. Not recommended for aquaponics.