Edible crop species differ *in their pH effect in hydroponics*

By understanding this process, growers can adjust fertilizer programs to stabilize pH and prevent plant loss.

By Ryan Dickson and Paul Fisher

FIG. 1 IS AN EXAMPLE of a common problem during hydroponic production of vegetable, leafy greens, and herb crops. Several leafy greens and herb seedling plugs were grown with separate fertilizer tanks. All tanks started with the same fertilizer recipe, complete with all essential nutrients. Nitrogen was supplied mostly (90%) as nitrate, with 10% of nitrogen as ammonium. After a few weeks, the arugula was stunted with the new leaves turning yellow and chlorotic (**Fig. 1**), which are typical symptoms of iron deficiency. Other crop species, which included lettuce, oregano and spinach, had no deficiency symptoms. The electrical conductivity (EC) of the nutrient solution was 1.8 mS/cm for all crops, indicating adequate nutrient levels. However, the nutrient solution-pH in systems containing arugula was 7.0, whereas the solution-pH for lettuce, spinach, and basil was 5.7 to 6.0. There were no signs of root disease.

This article explains why only the arugula raised pH and developed nutrient deficiency, even though all crops received the same fertilizer and growing conditions. By understanding this process, growers can adjust the fertilizer program, stabilizing pH and preventing plant loss.

Why care about pH?

The pH of a hydroponic solution influences the solubility and availability of nutrients for root uptake, especially iron and other micronutrients such as manganese and boron. A high pH decreases iron solubility and uptake by roots, which can result in deficiency symptoms as seen in arugula (**Fig. 1**). For most crops, keeping pH within a target range of 5.6 and 6.2 ensures adequate nutrient solubility and availability for plant uptake.

Fertilizer and plant species affect root zone pH

To understand why root zone pH sometimes drifts too high or low, research conducted at the University of Florida

Fig.1. Arugula leaf yellowing and chlorosis caused by iron deficiency at high pH

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evaluated species of vegetables, leafy greens, and herbs grown in a soilless peat substrate or a hydroponic nutrient solution. We grew the plants using three different fertilizers that varied in their proportion of ammonium to nitrate nitrogen. The acid (lowers pH) or base (raises pH) produced by plant roots, and the resulting change in pH was measured over several weeks.

Table 1 summarizes our research results. Across plant species, there was increasing acidity (and pH drop) as the proportion of nitrogen provided as ammonium increased from 0% to 40%, and the corresponding nitrogen provided as nitrate decreased from 100% to 60%.

Plant species differed in their tendency to raise or lower pH, even when supplied with the same fertilizer (**Table 1**). Arugula had the most basic effect, and cucumber was the most acidic.

	0% ammonium-N (100% nitrate-N)	20% ammonium-N (80% nitrate-N)	40% ammonium-N (60% nitrate-N)
Arugula	Strong basic effect (raised pH rapidly)	Basic effect (raised pH)	Basic effect (raised pH)
Pepper	Basic effect (raised pH)	Basic effect (raised pH)	Acidic effect (lowered pH)
Spinach	Basic effect (raised pH)	Basic effect (raised pH)	Acidic effect (lowered pH)
Eggplant	Basic effect (raised pH)	Neutral effect (pH was stable)	Acidic effect (lowered pH)
Tomato	Basic effect (raised pH)	Neutral effect (pH was stable)	Acidic effect (lowered pH)
Basil	Basic effect (raised pH)	Acidic effect (lowered pH)	Strong acidic effect (lowered pH rapidly)
Lettuce	Basic effect (raised pH)	Acidic effect (lowered pH)	Strong acidic effect (lowered pH rapidly)
Cucumber	Neutral effect (pH was stable)	Acidic effect (lowered pH)	Strong acidic effect (lowered pH rapidly)

Table 1. Plant species and fertilizer effects on root zone pH

Why is ammonium more acidic than nitrate?

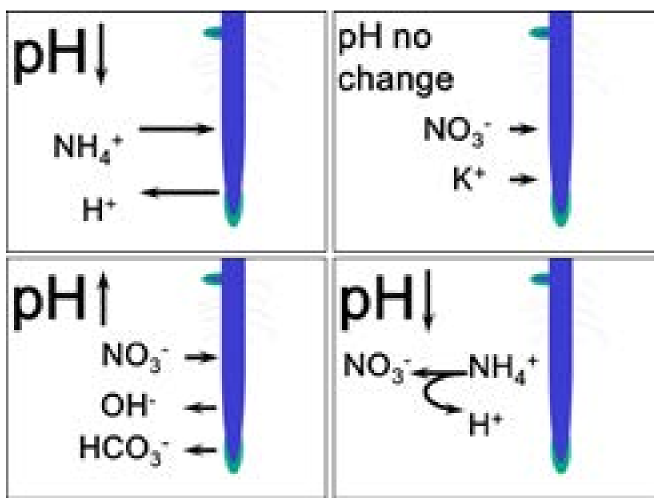

Fig. 2. Effects on substrate-pH from fertilizer uptake by roots. (A) Cation uptake is acidic. (B) Anion uptake is basic. (C) When roots take equal cations and anions, pH does not change. (D) Nitrification of ammonium by microbes is acidic.

When you mix a fertilizer in your hydroponic solution, the amount of ammonium nitrogen (NH_4^+) or nitrate nitrogen (NO_3^-) has little immediate effect on pH. The main pH effect of these nitrogen forms happens over time, after plant roots or microbes interact with fertilizer nutrients.

Plant roots take up "cations," which are fertilizer nutrients with a positive charge such as ammonium NH_4^+, potassium K^+, calcium Ca^{2+}, and magnesium Mg^{2+}. Plants also take up "anions," which are nutrients with a negative charge such as nitrate NO_3^-, phosphate $H_2PO_4^-$, and sulfate SO_4^{2-}.

When roots take up cations such as NH_4^+ the plant becomes more positively charged than the substrate. Plants balance the charge difference between the roots and substrate by exuding an acid (H^+) which drops the root zone pH (**Fig. 2A**).

Uptake of anions such as NO_3^- causes the plant to become negatively charged. Plants balance this charge by releasing base into the substrate (hydroxyl OH^- or bicarbonate HCO_3^-) which raises pH (**Fig. 2B**). Plants can also take up equal amounts of cations and anions, which results in no pH effect (**Fig. 2C**).

Nitrogen is especially important to root zone pH because (a) roots can take up nitrogen as a cation (ammonium NH_4^+) or anion (nitrate NO_3^-) and (b) plants require more nitrogen than any other fertilizer nutrient. Increasing ammonium in the fertilizer causes plants to take up more cations and produce more acid. Ammonium is a stronger acid than nitrate is a base, in

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Strategy	Concept	Potential downsides
Vary ammonium:nitrate ratio for different crops and water alkalinity levels.	Plants with a more basic effect, such as arugula, need more ammonium than other crops. Alkalinity (bicarbonates) increases solution pH. If solution pH is low, increase nitrate. If solution pH is high, increase ammonium.	Need for multiple recipes, soft growth with high ammonium fertilizer, possible ammonium toxicity, calcium levels may decrease as ammonium increases leading to tip-burn in lettuce and blossom-end rot in tomato.
In recirculating hydroponics, have one tank for multiple species rather than individual tanks for each species.	Simple system, where pH and fertilizer uptake differences are evened out.	May be too simple, where not able to optimize the nutrient solution for crops with different EC and pH needs.
If root zone pH is high, inject a mineral acid (sulfuric, phosphoric, or nitric acid) or citric acid into the nutrient solution.	Acid neutralizes alkalinity in irrigation water. Determine the amount of acid needed for fresh water using University of New Hampshire Alkalinity Calculator (**bit.ly/1NFIcAN**). Or use an automatic pH controller that injects small amounts of acid as needed.	Need chemical injector, inline pH meter, worker safety handling of caustic material. Changes nutrient balance (for example, nitric acid adds N, phosphoric acid adds P, sulfuric acid adds S). May over-shoot or under-shoot target.
If solution pH is low, and irrigation water alkalinity is naturally high, turn off acid injector.	Use natural alkalinity in fresh irrigation water to help bring pH up over time. Only inject acid if pH is high.	Not an option if irrigation water alkalinity is low (for example, if using reverse osmosis water).
When solution pH is low, and irrigation water alkalinity is low, increase alkalinity with a basic chemical such as potassium bicarbonate ($KHCO_3$) or potassium carbonate (K_2CO_3).	Alkalinity (raising pH and increasing buffering) can be increased by adding in a basic chemical. For hydroponic solutions, 1.3 ounces/100 gal (0.1 grams/liter) of $KHCO_3$ or 0.9 ounces/100 gal (0.07 grams/liter) of K_2CO_3 adds approx. 50 ppm $CaCO_3$ alkalinity. Or use an automatic pH controller that injects small amounts of base as needed.	Need chemical injector, inline pH meter, worker safety handling of caustic material. Changes nutrient balance (increases potassium). May over-shoot or under-shoot target.
Inline pH meter plus regular manual pH testing every 1 to 2 weeks	Monitor and act before plants are stressed. Manual pH meter is a check that inline pH meter is working correctly.	Need trained labor, inline and manual pH meters, and a maintenance and calibration schedule.
Use chelated iron-DTPA or iron-EDDHA fertilizers for crops sensitive to high pH, rather than iron-EDTA or iron sulfate (which are less soluble at high pH)	Supplementing micronutrients compensates for decreased solubility at high pH. 1 to 3 ppm of iron is typically required on a constant basis.	Increased fertilizer cost. pH does not just affect iron solubility. Ensure that there is no other nutrient imbalance (for example, deficiency in manganese or boron).
Periodically dump nutrient solution	Avoids major drift in the nutrient level and pH over time.	Wasteful, increasing fertilizer cost and possible environmental impact.

Table 2. pH management strategies for hydroponics

part because nitrifying bacteria present in the substrate convert ammonium to nitrate through a process called nitrification, which produces acid (**Fig. 2D**). Many plants also favor ammonium uptake over nitrate.

As an example of a commonly used fertilizer salt, potassium nitrate has 100% of nitrogen (N) in the nitrate form, so has a basic effect. In contrast, ammonium nitrate is 50% ammonium-N and 50% nitrate-N. Because ammonium is a stronger acid than nitrate is a base, ammonium nitrate is strongly acidic. Increasing the amount of nitrate sources in your fertilizer recipe relative to ammonium sources makes the solution more basic. You can increase acidity by increasing ammonium and reducing nitrate.

Why did arugula tend to raise root zone pH?

Plant species differ in their uptake of total cations and anions. Arugula tends to take up more anions, which produces base, and raises root zone pH. Cucumber tends to take up more cations, produces acid, and lowers pH. A "neutral" fertilizer for arugula contains about 35% of the total nitrogen as ammonium and the remainder (65%) as nitrate to stabilize pH. Other crops typically require less ammonium (10 to 30%) for a stable pH.

The other big pH factor in hydroponic solutions is alkalinity (primarily from bicarbonates dissolved in the source water). Alkalinity can be reduced with mineral acids or reverse osmosis, and varies depending on your water source. The neutral ammonium:nitrate ratios above assume reverse osmosis water (zero alkalinity). As alkalinity increases, the amount of ammonium or mineral acid required increases. Get a laboratory test of your irrigation water alkalinity. Check the University of New Hampshire Alk Calc (**bit.ly/1NFIcAN**) for recommendations for mineral acids needed to reduce alkalinity, and bring initial solution pH to around 6.

What can we do about our yellow arugula?

Our hydroponic arugula ran into nutritional problems because the roots of this species produced base and raised root zone pH to a level where iron was not soluble and available for uptake. Basil, lettuce, and cucumber were given the same fertilizer, but these species tend to be more acidic and did not push pH outside of an acceptable range.

There are several options to manage pH in a hydroponic solution summarized in **Table 2.** Keys to success are a combination of understanding crop effects on solution pH, the effect of ammonium versus nitrate on solution pH and other nutrients such as calcium, pH monitoring both inline and with a manual meter, and options to add acid or base to the irrigation solution. **pg**

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