e-GRO Edible Alert



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Fine-tuning nutrient replenishment in hydroponics

Controlling the electrical conductivity (EC) of recirculating nutrient solution is a simple and practical way to manage nutrient supply in hydroponics, and growers often aim to maintain a target EC level for a healthy crop (Figure 1). Solution EC is a measure of total soluble salts and provides an estimate of total nutrients in solution.

Common strategies to control EC include replenishing (i.e. “topping off”) the hydroponic reservoir with fresh nutrient solution and managing the strength of the replenishment solution, or topping off with clear water and frequently monitoring EC and injecting fertilizer as needed. The result is the same!

However, maintaining a constant solution EC does not guarantee an adequate, long term nutrient supply.

This e-GRO Edibles Alert provides a real-world scenario where maintaining a target solution EC resulted in nutrient deficiency. We will also discuss a method for designing replenishment solutions that minimizes the risk of nutritional problems and the need to periodically dump and replace solution.

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Figure 1. Example of a healthy head of lettuce grown hydroponically

Nutrient concentrations in solution ($mg \cdot L^{-1}$)							
Solution	EC (mS/cm)	N	P	K	S	Ca	Mg
Fresh Solution	2.00	190	144	309	266	157	44
3-week-old solution	2.24	60	329	446	817	101	69

Table 1. Example of differences in a hydroponic nutrient solution managed by maintaining EC over 3 weeks without replacement

Grower scenario

A commercial hydroponic grower came to us with reduced growth and yield of head lettuce (Figure 2). The grower topped off the hydroponic reservoir daily with fresh solution (Figure 3), aiming to maintain a solution EC between 1.8 and 2.2 mS/cm. Samples of their recirculating solution were collected immediately after mixing a fresh batch and after three weeks of production; solution EC and macronutrient concentration data are shown in Table 1.

Over time, the controlled solution EC was relatively stable and remained within range. However, there was significant accumulation of phosphorus (P), potassium (K), sulfur (S), and magnesium (Mg). Phosphorus concentration more than doubled and sulfur more than tripled! In contrast, nitrogen (N) was reduced.

Adding the fresh solution oversupplied phosphorus, potassium, sulfur, and magnesium for the lettuce crop, and over time the accumulation of these elements had a greater impact on root zone EC. In this scenario, nutrient supply was not balanced with plant demand, and the maintenance of a target EC resulted in less fertilizer being added back to the reservoir. Nutrient toxicity did not occur in this scenario, but the insufficient supply of nitrogen eventually reduced yield.

A potential answer to this problem is to dump and replace the hydroponic solution more often to maintain more constant and adequate nutrient levels. However, this is wasteful and costly. In addition, determining the "right" time and amount of solution to dump can be complicated.

Another option is to adjust the formulation of the nutrient replenishment solution to supply nutrients in the amounts and ratios required for growth, minimizing the need to dump and replace solution. With a nutrient solution more tailored to the crop needs, growers can maintain a target solution EC for longer without running into nutritional problems.

Figure 2. Multiple varieties of lettuce growing in a commercial NFT system

Figure 3. The nutrient solution reservoir for a commercial NFT system

Designing hydroponic replenishment solutions

Designing a hydroponic replenishment solution that matches nutrient supply with plant uptake demands is more easily said than done. At the University of Arkansas, we are experimenting with a new approach to designing solutions based on a few simple measurements taken in the greenhouse and using what are called "mass balance" principles. Below are some basic factors we measure:

1. Total plant growth (roots, leaves, stems, flowers, fruits)
2. Nutrient accumulation in plant tissues
3. Plant water use

Total plant growth is measured as the total dry weight of the whole plant. Most plants are about 90% water and 10% dry matter. In our research, we typically dry plants at 60-70˚C (140-158˚F) in an oven for two days. Commercial growers might measure growth by oven-drying a few extra plants at harvest, or estimate plant growth from the amount of harvested crop.

To measure nutrient accumulation in plant tissues, we suggest sending tissue samples to a testing laboratory. In this scenario, a whole-plant sample (roots, leaves, stems, flowers, fruits) is needed. Leaves typically have the greatest nutrient concentrations, and therefore only measuring leaf nutrients could influence results. Nutrients are reported in % or ppm of the dry weight.

Finally, a measure of the amount of water transpired by the crop for the amount of growth measured is needed. Many crops are reported to use approximately 0.2 to 0.4 mL of water per gram of dry weight gained. Water use differs between plant species, but is also heavily influenced by environmental conditions. In commercial practice, water used by the crop may be measured by installing water flow meters.

Measuring the % accumulated nutrients in dried plant tissues tells us the quantity of nutrients taken up per amount of growth. It also tells us the ratio of nutrients absorbed into the plant. For example, if potassium was measured at 4% and calcium at 2% in tissues, the ratio of potassium to calcium uptake was 2:1. Nutrient uptake ratios can be used to estimate nutrient ratios needed in the applied solution—this idea assumes roots are efficient at nutrient uptake and take up nutrients in the ratios supplied.

While the tissue analysis helps us determine the nutrient ratios to supply, measuring the volume of water transpired per amount of growth helps determine the replenishment solution strength and nutrient concentrations. Under very hot and dry conditions, for example, plants increase transpiration more than nutrient uptake, and nutrient concentrations and solution EC need to be lowered to prevent oversupply and salt accumulation. Plants transpire less water in cooler/wetter conditions, and nutrient concentrations need to be increased to prevent nutrient deficiency.

Individual nutrient concentrations in the replenishment solution can be calculated by multiplying the concentration of nutrients in dry plant tissues by the total plant growth, and then dividing by the total volume of water transpired.

Example calculation
Let's say a grower is harvesting head lettuce in winter. They select a few extra whole plants to oven-dry and determine the dry weight to be 1 kg. They check the water flow meters, and determine from sowing to harvest, it took 200 L (52.8 gallons) for those selected plants. The dried plants are analyzed for tissue nutrients and come back with 3.5% N, 0.8% P, and 3.0% K.

Nitrogen at 3.5% means 35,000 mg N per kg of dry weight (1% = 10,000 ppm). When multiplied by 1 kg dry weight and divided by 200 L, we learn the concentration of N in solution comes to 175 mg/L N (or 175 ppm-N). We would need 40 ppm-P and 150 ppm-K.

Let's say in summer it is hotter and drier, and it now takes 300 L per 1 kg of dry weight, but the % nutrients in the tissues are the same. The N concentration would change from 175 to 117 ppm-N, phosphorus from 40 to 27 ppm-P, and potassium from 150 to 100 ppm-K. Note that nutrient ratios are unchanged.

The nutrient concentrations are lower, but you would be topping off the reservoir more frequently, and supplying similar quantities of nutrients per plant and yield.

Conclusions

This method for designing replenishment solutions is a simple and more theoretical approach—which has both pros and cons. Our trials suggest this approach can reduce salt accumulation in recirculating hydroponic systems but a certain amount of fine-tuning is likely needed.

There are a number of other considerations with nutrient replenishment, some of which are included below:

- Irrigation water sources differ in nutrients supplied, EC, and alkalinity. Water quality will influence nutrient replenishment.
- Supplied nitrogen form (ammonium-N versus nitrate-N) affects nutrient uptake and root zone pH. Selection of the appropriate ammonium:nitrate ratio in solution is needed.
- Injection of mineral acid and base chemicals to control solution pH also adds nutrients. The solution ammonium:nitrate ratio can also be used to control pH.
- Plants can differ in nutrient requirements depending on growth stage, particularly fruiting crops. Nutrient replenishment may need to be adjusted between vegetative and reproductive growth stages.
- Replenishment solutions are crop specific. Growing multiple crops in the same hydroponic system may require adjustments and/or grouping of crops with similar nutrient requirements.
- Nutrient ratios in solution are sometimes controlled to promote plant quality, particularly the potassium:calcium ratio. Control of nutrient ratios may influence nutrient uptake and design of replenishment solutions.

For more information, be sure to check out this article by Dr. Bruce Bugbee at Utah State University (https://bit.ly/bbugbee2004); Dr. Bugbee provides a detailed look at developing replenishment solutions using mass balance principles and has decades of experience with this topic.

Literature used:

Bugbee, B. 2004. Nutrient management in recirculating hydroponic culture. Acta Hort. 648:99-112.

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