GREENHOUSE AND INDOOR PRODUCTION OF HORTICULTURAL CROPS

Details of Electrical Conductivity Measurements in Greenhouse Production

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To produce quality ornamental plants, it is important to monitor both the fertilizer concentration you supply to plants and the fertilizer status in the substrate. A popular method of measuring fertilizer concentration is using electrical conductivity (EC). Although this technique is popular, many growers don't entirely understand the concepts of EC.

This publication explains the details of EC for greenhouse growers.

What Is EC?

Electrical conductivity (EC) measures how well a fluid (water in the substrate) accommodates transport of electric charge (we'll discuss why this is important a little later). Figure 1 illustrates the concept of EC. When measured, solution to the left has a low EC value than the solution to the right. This is because, fertilizer ions (in the solution to the right) carry electrical charge and their presence increases conductivity of electricity through the solution.

Electrical conductivity is measured in Siemens (S) but 'mho's (opposite of 'ohm', the unit for resistance) are also occasionally used. Note that S = mho and one mS/cm = 1 dS/m = 1,000 µS/cm, where 'm' stands for 'milli', 'd' stands for 'deci' and 'µ' stands for 'micro'.

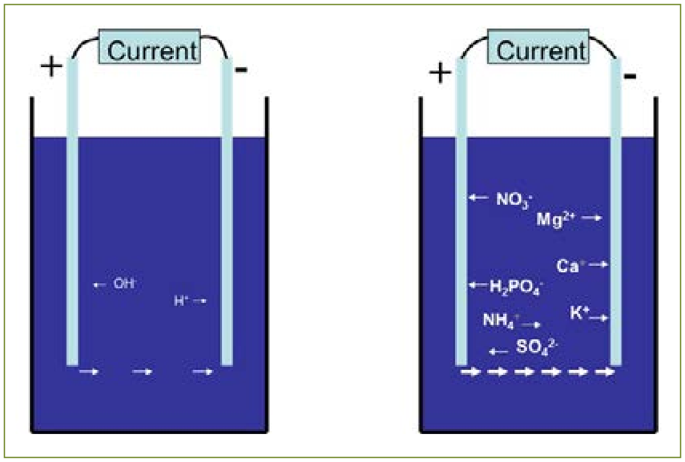

Figure 1. This illustration describes the concept of electrical conductivity in solutions. The solution on the left is pure water and does not contain fertilizer ions. The one on the right contains dissolved fertilizer salts. If you apply an electric current to the solution, the electrical charges carry that current in the solution. The more electrical charge the greater the electrical conductivity. The conductivity of the solution on the left is influenced by hydrogen and hydroxyl ions. The dissolved fertilizer salts in the solution on the right carry additional electrical charge. More electricity is conducted through the fertilizer solution, because there are more charged particles in it than in pure water.

Why Is EC Useful?

Electrical conductivity measurements are very useful in greenhouse production, because:

- You can measure the EC of a solution easily and quickly using affordable sensors
- The EC is proportional to the total amount of fertilizer salts present in a solution

It is important to note that EC indicates the total amount of fertilizer ions (nitrogen, phosphorus, and so on). But EC measurements are useful, because you can easily convert an EC reading to provide you with an accurate amount of nitrogen (N) in the solution (in parts per million, or ppm). However, this is done only for freshly prepared fertilizer solution.

To do this, you need to know the EC of the same fertilizer solution containing 100 ppm N. This information is usually available on the fertilizer bag (see Figure 2). Use this formula to measure nitrogen concentration in the fertilizer solution (as ppm N):

$$\text{ppm N} = 100 \times \frac{\text{EC of fertilizer solution} - \text{EC of irrigation water}}{\text{EC of fertilizer solution containing 100 ppm N}}$$

For example, a fertilizer solution is prepared with irrigation water containing an EC of 0.5 dS/m. The overall EC of the fertilizer solution is 2.5 dS/m and the EC of the same fertilizer solution containing 100 ppm N is 0.59 dS/m (per manufacturer label information on the bag, see Figure 4).

The concentration of N (ppm) in the fertilizer solution is:

$$\text{ppm N} = 100 \times \frac{\left[(2.5 - 0.5)\frac{dS}{m}\right]}{0.59\,\frac{dS}{m}} = 100 \times 3.39 = 339$$

Weight (in Ounces) of Product Needed to Mix One Gallon of Concentrate						
Target Fertilizer Concentration (N/ppm) After Dilution	Common Injector Ratios					EC (mmhot/cm) of Target Feed Rate After Dilution
	1:15	1:100	1:128	1:200	1:300	
25	0.3	1.7	2.2	3.4	5.1	0.15
50	0.5	3.4	4.3	6.8	10.1	0.30
75	0.8	5.1	6.5	10.1	15.2	0.44
100	1.0	6.8	8.6	13.5	20.3	0.59
125	1.3	8.4	10.8	16.9	25.3	0.74
150	1.5	10.1	13.0	20.3	30.4	0.89
175	1.8	11.8	15.1	23.6	35.4	1.03
200	2.0	13.5	17.3	27.0	40.5	1.18
250	2.5	16.9	21.6	33.8	—	1.48
300	3.0	20.36	25.9	40.5	—	1.77
350	3.5	23.6	30.2	47.3	—	2.07
400	4.1	27.0	34.6	—	—	2.36
450	4.6	30.4	38.9	—	—	2.66
500	5.1	33.8	43.2	—	—	2.95
600	6.1	40.5	—	—	—	3.54
— Exceeds maximum solubility.						

Figure 2. Fertilizer label showing the resultant electrical conductivity for a 100 ppm N concentration in the fertilizer.

The EC of a fertilizer solution can be used to check if a fertilizer injector is working properly. Fertilizer manufacturers provide information on how much quantity of fertilizer to be mixed with a gallon of water to obtain a certain EC using several common injector ratios (see Figure 2). Growers can verify if their fertilizer injectors are working properly using the manufacturer information and checking whether the EC of the resultant fertilizer solution agrees with manufacturer supplied information. If the resultant EC is within 10 percent of what is shown on the fertilizer bag, then the injector can be considered to be working properly.

Are There Problems with Using EC?

Plants take up different fertilizer ions at different rates from the substrate. For example, plants rapidly take up N, potassium (P), phosphorus (K), and manganese (Mn) ions; however, plants take up calcium (Ca), magnesium (Mg), and sulfur (S) ions more slowly (Bugbee, 2004). Because of this differential uptake, a fertilizer solution's EC in the substrate can be completely different in nutrient composition compared to the fresh fertilizer solution supplied to plants.

Understanding this can be very important if you used recycled fertilizer solutions in your production system. A common practice under recycling systems is to maintain the EC of the supplied fertilizer solution during production. The assumption is that by maintaining a target EC, you supply plants with nutrients at an optimal level. However, this may not be true in many recycled systems. Due to the differences in nutrient uptake, the composition of different elements in the recycled solution can be drastically different than those found in a fresh solution. Consequently, the recycled solution may not result in as balanced a recipe as the fresh solution.

In other words, adjusting the EC of the recycled solution using fresh solution does not result in the same composition that one would expect in a fresh fertilizer solution. Often, the EC of the recycled solution is largely influenced by fertilizer ions that are slowly taken up by plants and not necessarily by macronutrients like N, P, and K. The problem becomes intensified when a recycled solution is several days or weeks old. This situation can negatively affect plant growth (Figure 3). To avoid this, we recommend that you periodically (7 to 10 days) use fresh solution during growth.

How Do I Measure EC?

You can use a sensor to measure EC, but it is important to note that an EC sensor is only as good as its calibration. You should always calibrate your EC sensor before taking measurements on any day. Usually, new sensors come with calibration solutions that have a known EC. You can buy new sachets/bottles of calibration solution as needed.

Before using a sensor, pour a small volume of the calibration solution into a container and measure its EC by inserting the sensor into the solution. The measured EC should be within 5 percent of the

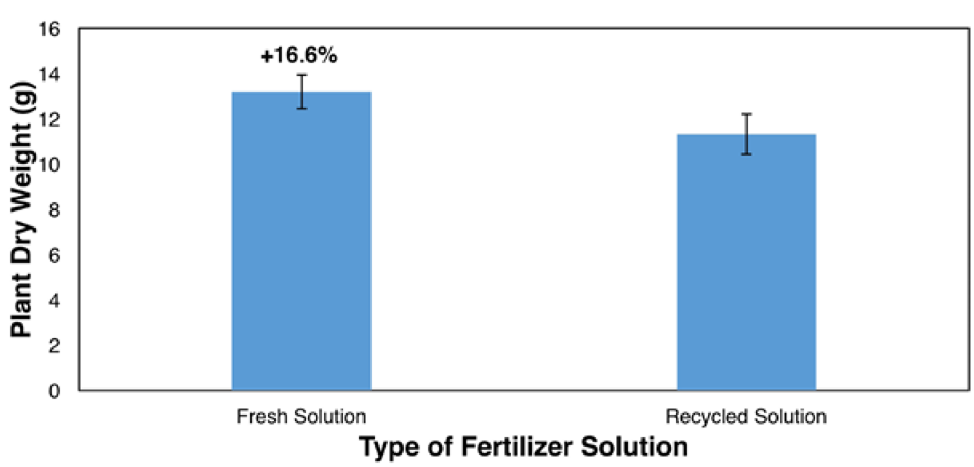

Figure 3. This graph shows the difference in the dry weight of hydroponically grown leaf lettuce under continuous supply of fresh (left) and recycled fertilizer solutions (right) in a greenhouse.

calibration solution's EC. If not, adjust the sensor to read as close as possible to the value of the calibration solution. After you adjust the sensor, measure the EC of the calibration solution one more time to ensure that the measured value is within 5 percent of the target.

Here are some important things to keep in mind when you calibrate an EC sensor:

1. Do not directly dip the sensor into the bottle of calibration solution. You will contaminate it.
2. Throw away the calibration solution you used — do not pour it back into the bottle. Again, this will contaminate the solution.
3. Make sure the calibration solution is not expired before you use it.

There are different sensors that can measure EC in solutions (such as fresh fertilizer solutions). Figure 4 shows EC sensors commonly used to measure a solution. These sensors are simple to use: you either you dip the electrode directly into the solution or pour solution into the cup connected to the electrode.

Figure 4. Some EC sensors commonly used for measuring a solution.

You can measure the EC of the substrate (what is available to plants) by collecting the solution from the substrate pores (pore-water conductivity) or inserting sensors into the substrate (bulk water conductivity, measurement includes conductivity of the substrate particles and air in addition to fertilizer solution in the substrate). You can measure pore water conductivity using the EC sensors described for fertilizer solution.

There are three methods available to collect pore water for substrate EC measurements (Table 1 compares the values from these methods; Cavins et al., 2000):

1. **The 1:2 dilution method.** With this method, you collect a sample solution from the top of the container by mixing one part of the substrate in two parts of distilled water and allowing substrate to settle at the bottom.
2. **The SME method.** With this method, you collect solution by slowly mixing distilled water, stirring the substrate until it is saturated (a glistening water layer appears on top of the substrate). You then filter the solution from the saturated paste.
3. **The pour-through method.** With this method, you collect leachate from the bottom holes of the container by pouring a small volume of distilled water at the top of a substrate, which is thoroughly irrigated, pushing water out of the substrate pores.

More information about the pour-through method is available in *Greenhouse and Indoor Production of Horticultural Crops: Pour-through Technique of Measuring Electrical Conductivity of the Substrate* (Purdue Extension publication, HO-285-W), available from the Education Store, edustore.purdue.edu.

Table 1. Comparative values from different methods of measuring substrate EC.

Substrate-based EC Measurement Techniques			
1:2	**SME**	**Pour-through**	**Indication**
0-0.3	0-0.8	0-1.0	Very Low
0.4-0.8	0.9-2.0	1.1-2.6	Low
0.9-1.3	2.1-3.5	2.7-4.6	Normal
1.4-1.8	3.6-5.0	4.7-6.5	High
1.9-2.3	5.1-6.0	6.6-7.8	Very High
> 2.3	> 6.0	>7.8	Extreme

Figure 5 shows the sensors commonly used to directly measure the EC of a substrate. Just like the other types of EC sensor, you should calibrate the sensor before using it. Experience shows that substrate measurements can vary significantly within a container. For this reason, we recommend taking at least three measurements from a container, and averaging the measurements.

Some sensors measure substrate EC from the region that is in contact with the tip of the probe. In this case, it is useful to insert the probe at different depths and measure EC. Exercise care while inserting the probes into the substrate, because you can easily damage the electrode at the tip.

Other sensors measure the substrate EC in a small cylindrical volume along the length of the probe. These sensors are usually more expensive but the measurements are more reliable. Be aware that the substrate's moisture content can affect the direct substrate EC measurement, so consider making bulk EC measurements from substrates that have a similar moisture content.

When measuring substrate EC as part of routine production, we recommend that you adopt a standard procedure for sampling the crop. Consider these guidelines:

1. Always sample plants with different fertilizer requirements separately
2. Sample five pots or cell packs per 1,000
3. Randomly select plants during sampling
4. Select plants from the interior of the bench
5. Separately sample plants at different growth stages (active vs. slow growth and vegetative vs. bloom stages)

The goal of EC monitoring is to maintain optimal nutrient levels in the plants. The concentration of different essential elements in the plant tissue influences optimal growth. Maintaining the recommended EC levels for a crop should result in the optimum tissue nutrient levels described below. You can determine plant nutrient levels by collecting leaf samples and analyzing them in a laboratory.

Figure 5. Some EC sensors commonly used for measuring substrates.

Table 2. Optimal levels of macronutrients in plant tissue (as % or mg/g tissue).

Nitrogen	Phosphorus	Potassium	Calcium	Magnesium	Sulfur
2.5-4.0	0.4-1.0	2.5-4.0	1.0-2.5	0.25-1.00	0.2-0.7

Table 3. Optimal levels of micronutrients in plant tissue (ppm).

Iron	Manganese	Boron	Copper	Zinc	Molybdenum
50-120	50-300	25-75	5-25	25-100	0.2-1.0

Doing this at least once for different species can ensure that the EC levels you supply will result in optimum nutrient levels in your plants.

Tables 2 and 3 provide information about optimal levels of different nutrients for a range of plant species (Mills and Jones, 1996).

References

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