Monitor, Record, Adjust:

Conductivity in Hydroponics (Part I)

by Andrew Taylor: Chemist for Flairform

Because hydroponic nutrient mixtures are usually composed completely of salts, their approximate concentrations can be determined via conductivity values. However, because each individual nutrient has its own specific conductivity value, and the concentration ratios between nutrients are continuously changing, conductivity readings need careful interpretation. Only significant differences in day-to-day conductivity values may be important.

Nevertheless, when intelligently used, conductivity values are a valuable monitoring aid. Further, it is far preferable to quote conductivity values rather than TDS to monitor changes in hydroponic nutrient concentrations. Converting conductivity values to TDS is unnecessary and prone to large interpretation errors.

What is Conductivity (EC)?

Conductivity represents the ease with which a solution conducts electricity. Numerically it is measured in units called siemens. Solid substances known as salts (e.g. sodium chloride, potassium nitrate), yield ions when dissolved in water. Ions permit the flow of electricity through the solution. Increasing the concentration of ions improves the ease with which the solution carries a current and, therefore, causes a higher conductivity.

Liquids such as petrol and pure water are essentially non-conductors of electricity. Further, many water-soluble substances do not conduct electricity when dissolved in water. This occurs because these liquids/solutions contain very few ions.

How EC is measured?

A conductivity meter or EC meter (also known as mS, cF or TDS meter) is a device used to help monitor the concentration of nutrient solutions.

Figure 1:
Popular styles of conductivity meters: Availability ranges from the more expensive laboratory grade (left), to the cheaper, pocket-sized (right).

"Because liquids contain very few ions, many water-soluble substances will not conduct electricity when dissolved in water."

A conductivity meter is essentially an "amp meter." Two plates made of inert metal (palladium-coated platinum) are placed in the sample; an alternating current voltage of around 1,000 cycles per second is applied across them and the current is measured (*Figure two 'a'*).

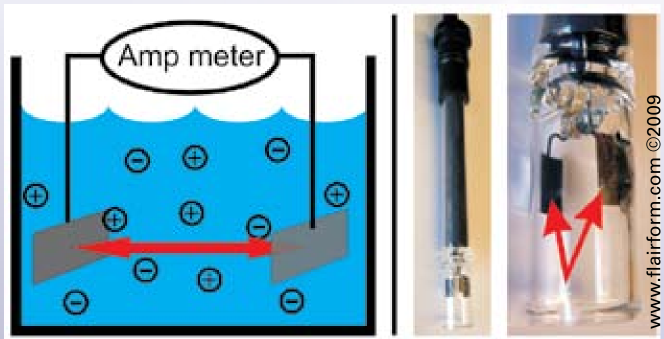


Figure 2a: Basic illustration of conductivity meter.
Figure 2b: Laboratory electrode - arrows highlight the palladium coated platinum electrodes.

Conductivity (G) is the inverse of resistivity (R) and is determined from the voltage (E) and current (I) values according to Ohm's law: $G = 1/R = I/E$.

Since the charge on the ions in a solution permits the conductance of electrical current, for most solution types the conductivity will increase with concentration. Thus, an EC meter can be used to detect the presence of salts and their approximate concentration in a solution.

Units of measure for EC

EC meters, nutrient labels and general literature represent conductivity values in several ways. The more common units are:

- mS/cm (often abbreviated as "mS"). Pronounced "milli-siemens per centimeter."
- µS/cm (often abbreviated as "µS"). Pronounced "micro-siemens per centimeter."
- cF (conductivity factor).
- ppm* (parts per million) or mg/L (milligrams per liter).

These both have the same numeric value. These are the units for "total dissolved salts" (TDS). Meters that provide these units have internal software that mathematically converts conductivity readings into a TDS estimate. However, this estimate is prone to many errors and therefore its use should be avoided.

To utilize conductivity recommendations you must first know what units your meter operates in. This will be displayed on either the digital display or stamped on the body of the meter. Some brands offer multiple options (e.g. cF, mS and uS). If this is the case, choose the option that matches that used on the nutrient label – or the recommendation you were given. For example, if a nutrient label specifies "mS" then switch the meter to read "mS."

If your meter is incapable of producing units that match the conductivity recommendation, then manually convert the values to match (see Table one). For example, if the label gives a recommendation of 2.0 mS but your meter only works in cF, then convert the recommendation to cF by multiplying it by 10 (2.0 mS x 10 = cF 20).

Table 1: Interconversion factors
uS/cm ÷ 1000 = mS/cm
cF ÷ 10 = mS/cm
mS/cm x 1000 = uS/cm
cF x 100 = uS/cm
mS/cm x 10 = cF
uS/cm ÷ 100 = cF
Note, mhos (Ω) and siemens (S) are equivalent units e.g. mS/cm = mΩ/cm

Factors affecting the EC value

The actual conductivity value of an aqueous solution containing a single salt is determined by the concentration of that salt, the solution temperature and the nature of the particular salt.

> "If the concentration of dilute solutions of soluble salts is doubled, its conductivity usually also doubles."

i. Concentration effect

With relatively dilute solutions of soluble salts up to 100 ppm or so, if the concentration is doubled, its conductivity usually also doubles. At higher concentrations, however, this strict proportionality deteriorates (*see Table two*). Note there is a better linear relationship between concentration and conductivity from one to two grams per liter compared to 10 and 20 grams per liter.

Table 2. Conductivity values given by increasing concentrations of a hydroponic "Grow" nutrient dissolved in distilled water.	
ml/L of nutrient	**Conductivity** (mS/cm at 77ºF)
1	0.33
2	0.64
4	1.21
10	2.81
20	5.24

A consequence of this linearity feature is that simple arithmetic can be used to calculate the approximate conductivities, which would result from mixing different solutions of known conductivities. For example, if a 2.0 mS/cm water is diluted with an equal amount of distilled water (zero mS/cm), the result would be approximately 1.0 mS/cm. Similarly, if 100 milliliters of a 4.8 mS/cm nutrient solution is diluted with 900 milliliters of 0.40 mS/cm water (i.e. one plus nine), the expected result would be about 0.84 mS/cm (i.e. 100/1,000 x 4.8 + 900/1,000 x 0.40).

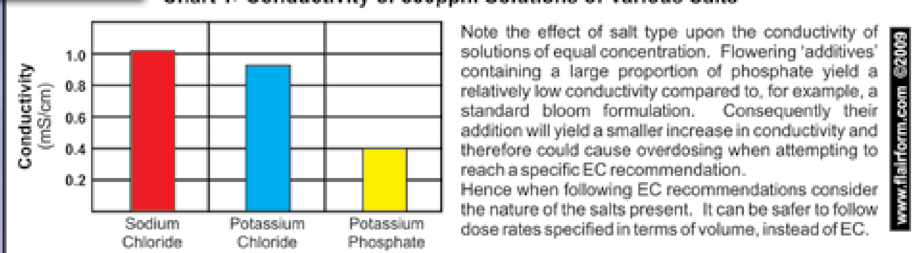
ii. Temperature effect

The effect of solution temperature on conductivity is such that its value rises by about two per cent (compounded) for each one degree increase. However, most meters automatically apply a correction factor to the determined value such that the displayed value is as if the solution temperature was at 77ºF.

iii. Effect of salt type

The conductivity of different salts varies widely and is determined by such factors as the size of the ions, and the charge density on these particles whilst in solution. For example, the conductivities at 77ºF of 500 ppm aqueous solutions of sodium chloride, potassium chloride and potassium phosphate are 1.02 mS/cm, 0.95 mS/cm and 0.40 mS/cm respectively *(Chart one)*.

Chart 1: Conductivity of 500ppm Solutions of Various Salts



Notably, the potassium phosphate solution has less than half the conductivity of a sodium chloride solution of equal concentration. Further, notice how potassium when combined with chloride (as potassium chloride) has a lower conductivity than what sodium does when combined with chloride (as sodium chloride). This is mainly because a 500 ppm solution of potassium chloride has about 30 per cent fewer ions to carry the current than a 500 ppm solution of sodium chloride – due to the fact that the combined mass of potassium and chloride is 30 per cent heavier than sodium chloride. Similarly, a 500 ppm solution of potassium phosphate has only 40 per cent of the number of ions than in the sodium chloride solution.

> "500 ppm solution of potassium chloride has about 30 per cent fewer ions to carry the current than a 500 ppm solution of sodium chloride."

"Additives that claim to be 100 per cent organic should contain no salts and their addition would produce no increase in conductivity."

The impact of salt type upon the EC value is further emphasized when the EC of typical uncontaminated waters is compared with that of an inorganic nutrient solution of equal concentration. For example, an uncontaminated bore water containing 1,000 ppm of salt will typically yield an EC of 1.8mS/cm. However, an inorganic nutrient solution of the same EC will in fact contain 1,600 ppm of salt. The reason for this is inorganic nutrient mixtures have much higher concentrations of the heavier substances like potassium and phosphate. Bore waters, however, typically contain numerically more ions of lighter salts like sodium and chloride. The important point here is that the electrical mobility of these ions in water is not that different; it is the total number present that determines the conductivity.

Hence, when following EC recommendations in hydroponics, consider the composition of all additives. Flowering additives that contain a large proportion of phosphate yield a relatively low conductivity. Consequently you need to be aware that their addition will produce less increase in conductivity than a normal inorganic nutrient mixture. Also, note that additives that claim to be 100 per cent organic should contain no salts and their addition would produce no increase in conductivity.

It should be emphasized that conductivity measurements determine total dissolved salts only – not total dissolved solids. This is because the presence of solids and substances such as organics, clay, tannins, algae particles, precipitates, color etc., will not affect the measured conductivity. Total dissolved solids can only be determined by evaporation methods. **MY**

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