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Pathways to precision in soil analysis: advancing soil laboratories in Latin America and the Caribbean

Caminos hacia la Precisión en el Análisis de Suelos: avance de los Laboratorios de Suelos en América Latina y el Caribe

Soil EC determination

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Principles Electrical Conductivity (EC)

- The fundamental principle behind the electrical conductivity is the ease of movement of electrons through a material.
- Electrical conductivity (EC) is the property of the material by which these electrons can move through the material.
- The EC is a numerical expression of the inherent ability of a medium to carry an electric current.

Factors that affect EC values

- The EC is affected by the sample's temperature and by the mobility, valences, and relative concentrations of each ion in the solution (water itself is a very poor conductor of electricity).

- Ion pairs that are less charged contribute proportionately less to electrical conduction than when fully dissociated.

Electrical resitance “R”

The **electrical resistance “R”** is directly proportional to the distance “L” between the electrodes and inversely proportional to the cross-sectional area “A” of the conductor.

If L = 1 cm and A = 1 cm^2 then R (electrical resistance) = r.

Where r is called specific resistivity.

Hence specific resistance (Rs) is the resistance of a conductor 1 cm in length (L) and 1 cm^2 in area (A).

Cell constant (K)

- Because practical cells are not of this dimension (L = 1 cm and A = 1 cm^2) measure only a given fraction of the specific resistance (Rs).
- The measured fraction of the specific resistance (Rs) is called cell constant (K).
- Therefore cell constant (K) represents the ratio between R (measured resistance) and Rs (specific resistance):

$$\mathbf{K = R/Rs}$$

- When the cell constant is applied, the measured conductance is converted to specific conductance (i.e., the reciprocal of the specific resistance) at the temperature of measurement.

Electrical conductivity and electrical resistance

- The EC determination generally involves the physical measurement of the material’s **electrical resistance (R),** which is expressed in ohms.
- The reciprocal of resistance is conductance (C). It is expressed in reciprocal ohms, i.e., mhos.
- The magnitude of the measured electrical resistance depends on the dimensions of the conductivity cell used to contain the sample and the electrodes.

Rhoades et al., 1999

Electrical Conductivity Units

- Electrical conductivity has been customarily reported in micro-mhos per centimeter (µmho/cm) or milli-mhos per centimeter (mhos/cm).
- In the International System of Units (SI), the reciprocal of the ohm is the Siemens (S). This system reports electrical conductivity as Siemens per meter (S/m) or as decisions per meter (dS/m).

  One dS/m is equivalent to one mmho/cm.

Rhoades et al., 1999

Electrical Conductivity and temperature

- The EC increases at a rate of approximately 1.9% per degree centigrade increase in temperature.

- Therefore, EC needs to be expressed at a reference temperature for purposes of comparison and accurate salinity expression; 25° C is most commonly used in this regard.

Rhoades et al., 1999

Temperature coefficient (ft)1

- For practical purposes of agricultural salinity appraisal, EC is measured at one known temperature other than 25° C and then adjusted to this latter reference using an appropriate temperature coefficient (ft).

- Temperature-coefficient (ft) vary for different salt solutions but are usually based on NaCl solutions since their "ft" closely approximate those of most salt-affected surface, ground, and soil waters.

Rhoades et al., 1999

Temperature coefficient (ft)2

- Another limitation in using “ft” to adjust EC readings to 25° C is that they vary somewhat with solute concentration.
- For practical needs, the value of “*ft*” may be estimated as:

ft = 1 - 0.20346 (T) + 0.03822 (T2) - 0.00555 (T3)

where T = (temperature in degrees Celsius – 25) /10

* This relation was derived from data given in Table 15 of Handbook 60 (US Salinity Laboratory Staff, 1954).

Rhoades et al., 1999

Temperature coefficient (ft)3

In turn, the electrical conductivity at 25° C, EC_{25}, is calculated as:

$$\mathbf{EC_{25} = ft * ECt}$$

where ECt is the EC at the measured temperature “t”.

- ❖ The above approach and ft - temperature relations have been routinely used to reference soil electrical conductivity values (Rhoades, 1976), as well as solution/extract conductivities.
- ❖ The applicability of these “ft” factors were tested for their appropriateness in this regard and concluded to be appropriate by McKenzie, et al. (1989), Johnston (1994), and Heimovaara (1995).

Rhoades et al., 1999

Electrical Conductivity in soils 1

- EC has its historical roots in the measurement of soil salinity.
- Whitney *et al.*, (1987) attemted to infer soil water content and salinity from measurement of soil resistivity using two –probe electrodes.
- The EC was considered more useful than resistance for measuring salinity because the increases in salt content depending on which makes it easier to interpret the results.

Electrical Conductivity in soils 2

- Soil electrical conductivity (EC) measures the ability of soil water to carry an electrical current, which is directly related to the number of dissolved salts and ions (nutrients) in the soil.
- Because the EC and total salt concentration of an aqueous solution are closely related, EC is commonly used as an expression of the total dissolved salt concentration of an aqueous sample and is indicative of soil salinity (Rhoades *et al.,* 1999).

Principles of EC determination in soils

- The salts in solutions offer some resistance to the passage of electric current through them.
- The higher the salt content, the higher the passage of current and the lesser the resistance to the flow of the current.
- As the amount of the soluble salts in a solution increases the electrical conductivity also increases.

Measurement of Electrical Conductivity (EC) in Soil

- The EC is most easily measured by applying a known DC voltage across the pair of parallel electrodes immersed in the soil suspension of water, measuring the current produced, and calculating the resistance in the volume bounded by the electrodes.
- Electrical conductivity (EC) is determined with a conductivity bridge and cell by measuring the electrical resistance of a 1:5 soil: water suspension.
- Soil-water extracts are most commonly used: ratio 1:1 ($EC_{1:1}$), 1:2 ($EC_{1:2}$), 1:5 ($EC_{1:5}$) and 1:10 ($EC_{1:10}$) soil to-wáter-mixtures.

Soil-water extract and saturated paste (SP)

- The soil-water extract is greatly affected by soil texture, and adding water has a significant impact on the measurement results.
- The saturated paste (SP) is more closely linked to natural soil conditions, taking into account the effect of dilution on ion concentration and conductivity induced by different soil-water ratios, and can minimize the effect of dilution on the degree of variation in ion ratios in natural soil solutions. But it is usually difficult and time-consuming to obtain.
- The EC of SP extracts (EC_e) is the best indicator of plants' response to salinity and is recommended as the standard laboratory method for estimating soil salinity (Herrero and Pérez-Coveta, 2005).

Qingyi Wang et al., 2023)

Instrument for measuring EC

- The conductivity instrument (conductivity bridge) is equipped with a conductivity cell.
- The instrument should have an automatic temperature compensation device and the precision of each measurement should be ± 1 mS m^{-1} at 20 °C.
- It is also an advantage if the cell constant is adjustable.

Johnsson et al., 2005

The control of the cell constant

❖The cell constant of the instrument is controlled by using KCl solutions with known EC values:

- 1290 mS m^{-1} (0.10 mol L^{-1}),
- 277 mS m^{-1} (0.020 mol $^{-1}$)
- 141 mS m^{-1} (0.010 mol $^{L-1}$),

all at 25 ^{o}C

Johnsson et al., 2005

Interferences

- Polluted electrodes or air bubbles may compromise the accuracy of the measurements.
- When EC < 1 mS m^{-1}, atmospheric carbon dioxide (CO_2) or ammonia (NH_3) may have an influence on the measurements.

Johnsson et al., 2005