

Cation Exchange Capacity of Soil

A common enquiry to ARL is what is Cation Exchange Capacity (CEC) and how do we measure it.

ARL provides CEC and Base Saturation (BS) information as part of the standard suite of tests.

Definitions

Cation Exchange Capacity (CEC)

CEC is defined as the sum total of the exchangeable cations (me/100 g) that a soil can absorb or hold. In effect, it is a measure of the negative charge on the soil.

Exchangeable Bases

The exchangeable bases relevant to agriculture which is also the most abundant cations are Calcium, Magnesium, Potassium, Sodium and Aluminium that is associated with acidic soils.

Base Saturation %

The Total Exchangeable Bases or CEC is the sum of the exchangeable bases (Ca, Mg, K, Na and H) in me/100g absorbed or held by the soil. Base saturation % for the individual bases is expressed as a percentage of the CEC.

Background

Soil can be considered a natural exchange resin capable of carrying both negative and positive electrostatic charges. These charged sites act as exchange sites for nutrient ions that can either be positive or negatively charged. The cations (positive ions) are attracted to the negatively charged sites on the soil and the anions (negative ions) are attracted to positively charged sites. Examples of positively charged ions (cations) include: calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+), sodium (Na^+), hydrogen (H^+), ammonium (NH_4^+), manganese (Mn^{2+}) and aluminium (Al^{3+}). Humus or soil organic matter is highly negatively charged and contributes significantly to the CEC of soil.

Factors that affect the total charge (both positive and negative) of a soil are the type of clay minerals, the total clay content, organic matter content and the soil pH. Because it is the properties of the particulate surface that attribute the overall electrostatic charge, it is the finest soil particles, both organic and inorganic, that determine the total exchange capacity. For this reason, sand and gravel play little part because of their small surface

to weight ratio. Thus, the higher the clay content and organic matter content, the higher the CEC of the soil and the ability to hold nutrients.

Measuring CEC

Dried and ground soil is extracted with a concentrated (1M) ammonium acetate solution buffered at pH 7 using a soil/solution ratio of 1:20 and mechanical shaking for 30 minutes. Ammonium ions displace the resident cations from the soil surface into the extraction solution. After filtration, the resulting quantities of calcium, magnesium, potassium and sodium in solution is measured on an MP-OES or ICP-MS.

The change in pH of the extraction solution is also measured to estimate the exchangeable hydrogen concentration (me/100g), followed by calculation of the CEC by summation of the exchangeable cations and hydrogen. Measuring and ascribing exchangeable hydrogen in this way is debatable when modern knowledge of soil chemistry is considered, but from a commercial laboratory perspective it is a cost-effective procedure for providing an estimate of the CEC. This CEC is then used for calculation of base saturation percentages.

Alternatively, the true CEC at field pH can be determined using the process described by Schollenberger and Simons in 1945. This is a separate and dedicated procedure for measuring CEC involving exchanging the resident cations with ammonium ions, washing the soil with alcohol to remove excess ammonium ions, displacing the ammonium ions from the soil surface with sodium and measuring the displaced ammonium in solution. This is not a method offered by commercial laboratories in New Zealand since it is time consuming, expensive and does not contribute to better management of soil fertility levels.

ARL reporting

CEC and base saturation

CEC is reported as me/100g and is the sum of Ca, Mg, K, Na and hydrogen ions. Observed values can be as low as 5 me/100g for sandy soils to as high as 90 me/100g for raw peat soils. Base saturation is expressed as a percentage of the CEC:

$$\text{Calcium base saturation \%} = \frac{(\text{Ca me/100g})}{(\text{CEC me/100g})} \times 100$$

Though we report Total Base Saturation % and % Base Saturation (BS %) for each of the cations, most plants tolerate a very wide range of BS % ratios. As a general recommendation various authors have defined normal values for the exchangeable bases as 60 to 80% for Ca, 10 to 20% for Mg, 2 to 5% for K, and 10 to 20% for Hydrogen.

MAF Quick Test (QT)

QT values is an index used to express the quantities of the exchangeable cations, Ca, Mg, K and Na in the soil. Field calibration work for determining optimum nutrient levels for crop production in New Zealand is based on MAF QT values. The perfect relationship between MAF QT values and the amount nutrients expressed in kg/ha, results in MAF QT being a robust index for managing soil fertility grounded on the principle of sufficiency of supply.

me/100g

ARL soil reports also show Exchangeable Ca, Mg, K and Na reported in me/100g. These values can be converted to mg/kg using the following equations:

$$\begin{aligned} \text{Calcium me/100g} \times 200 &= \text{Ca mg/kg} \\ \text{Magnesium me/100g} \times 122 &= \text{Mg mg/kg} \\ \text{Potassium me/100g} \times 391 &= \text{K mg/kg} \\ \text{Sodium me/100g} \times 230 &= \text{Na mg/kg} \end{aligned}$$

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Additional notes

In New Zealand topsoil's are the only cations used to calculate CEC are calcium, magnesium, potassium, sodium and hydrogen. Considering the methods of measurement used no other cations would be present in significant enough concentrations to materially affect the CEC. At pH values below 5.5 levels of exchangeable Al^{3+} may be present at levels that can affect CEC but that is accounted for by the hydrogen measurement.

Most soils are variable charge soils, meaning that as the pH is increased with liming the CEC also increases. These additional negative charged sites are occupied by calcium and magnesium from the lime.

As sodium exceeds 10% of the exchangeable cations there will be a noticeable breakdown of structural soil aggregates accompanied by decreased permeability. In New Zealand this would be associated with coastal soils.

Reference: Schollenberger, C.J. & Simon, R.H. 1945. Determination of exchange capacity and exchangeable bases in soil - ammonium acetate method. Soil Science 59, 13-24.

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