Cation exchange capacity and base saturation

LAST MODIFIED: SEPTEMBER 20, 2018

The soil particles are electrically charged and can therefore bind different ions that are dissolved in the soil liquid at their surface. The binding is unspecific, any charged ion having a charge opposite to that on the surface can participate in the bond. An ion is also not bound to any particular charge on the particle surface. The electrostatically bonded ions are interchangeable and can replace places with other positively charged ions.

Provtagning av mineraljordshorisonter. Foto: Gunnar Odell.

Cation Exchange Capacity

Cations (+) are bound to negative and anions (-) to positive soil charges. The soil's ability to bind cations to particle surfaces is called cation exchange capacity (CEC, after the English term: Cation Exchange Capacity). For anions, the equivalent term is called anion exchange capacity (AEC, after the English expression: Anion Exchange Capacity).

In Sweden, most soils have significantly higher CEC than AEC. One consequence of this is that cations bind better in the soil than anions. Examples of replaceable cations are calcium (2+), magnesium (2+), potassium (1+), ammonium (1+), hydrogen (1+), aluminum (3+). Anions are e.g. sulfate (2-), nitrate (1-), chloride (1-) and phosphate (3-). The numbers in brackets indicate the charge of the ions.

The amount of ions that bind is dependent on the ion charge

The exchange capacity unit is $cmol_c * kg^{-1}$ (centimol charge per kg soil). However, often the yield capacity is stated in $mmol_c * kg^{-1}$ (ie millimole charge per kg soil), or $meqv * kg^{-1}$. Mol is an SI unit for the substance quantity. One mole of a substance contains a certain number of elements (atoms, molecules). This number is equal to Avogadros constant ie about $6.022 * 10^{23}$. The amount of ions that bind per surface charge is dependent on the ion charge. A certain surface charge can thus bind twice as many potassium ions as calcium ions because potassium is present as monovalent ion while calcium is bivalent. For this reason, the replacement capacity unit is indicated as millimole charge instead of the corresponding amount of ions.

Clay minerals and humus determine the soil's bonding ability

The soil's capacity to bind ions is mainly linked to the small particles, mainly clay minerals and humus. Humus particles have a large inner surface where ion exchange processes can take place. Clay-rich and humus-rich soils generally have high values for CEC and AEC. Soils rich in precipitated iron and aluminum oxides have especially high AEC. Organic material in the humus layer can have CEC around 1000 $mmol_c\ kg^{-1}$. The CEC of the clay mineral varies between 100 and 1500 $mmol_c\ kg^{-1}$.

Maps of cation exchange capacity in Swedish woodland 1993-2002

Maps of the degree of saturation (BSpH = 7) in Swedish woodland 1993-2002

Maps of effective base saturation (BSeff) in Swedish forestland 1993-2002

Determination of cation exchange capacity

If the concentrations (in $mmol_c\ kg^{-1}$) of the interchangeable base cations (Ca^{2+}, Mg^{2+}, K^+ and Na^+) are summed and the total acidity (TA) is obtained, the cation exchange capacity (CEC) of the sample is obtained:

$$CEC = \sum (Ca^{2+} + Mg^{2+} + K^+ + Na^+ + TA)$$

The cation exchange capacity size increases with the pH. Therefore, the cation exchange capacity can be stated in two different ways. In the expression above, the content of exchangeable cations and total acidity at pH 7 has been determined. The value of the cation exchange capacity then obtained is sometimes referred to as potential cation exchange capacity or CEC_{pH7}. The cation exchange capacity at the soil's actual pH is called effective cation exchange capacity (CEC_{eff}). This CEC value can be determined with an unbuffered extractant (eg NH_4Cl) and is sometimes used when the soil has a pH value well below pH 7. A certain estimate of CEC_{eff} can be obtained by adding the exchangeable base cations (extracted with 1N NH_4OAc solution, buffered to pH 7.0) with replaceable aluminum (extracted with 1 M KCl solution):

$$CEC_{eff} = \sum (Ca^{2+} + Mg^{2+} + K^+ + Na^+ + Al_{KCl})$$

base saturation

The total base saturation rate (determined at pH 7.0) is a measure of how much of the cation exchange capacity (CEC) is made up of base cations and is usually expressed in percent (%):

$$BS_{pH7} = \frac{100 * \sum(Ca^{2+},\ Mg^{2+},\ K^{+},\ Na^{+})}{\sum(Ca^{2+},\ Mg^{2+},\ K^{+},\ Na^{+},\ TA)}$$

, where Ca $^{2+}$, Mg $^{2+}$, K $^{+}$ and Na $^{+}$ are exchangeable base cations and TA = total acidity.

The effective base saturation rate (BS_{eff}) corresponds to the base saturation rate at the soil pH and is calculated by the following expression:

$$BS_{eff} = \frac{100 * \sum(Ca^{2+},\ Mg^{2+},\ K^{+},\ Na^{+})}{\sum(Ca^{2+},\ Mg^{2+},\ K^{+},\ Na^{+},\ Al^{3+})}$$

, where Al $^{3+}$ is interchangeable aluminum determined by extraction with 1 M KCl solution.

Even the effective base saturation rate (BS_{eff}) is usually given in percent (%).

Contact

Johan Stendahl , Associate Professor
Department of Soil and Environment, SLU
johan.stendahl@slu.se , 018-67 38 01