Soil Exchangeable Bases (ammonium acetate method)

Introduction

The amount exchangeable bases and the cation exchange capacity (CEC) are important properties of soils and sediments. They relate information on a soil's ability to sustain plant growth, retain nutrients, buffer acid deposition or sequester toxic heavy metals. Cation exchange occurs due to the negative charges carried by soil particles, in particular clay minerals, sesquioxides and organic matter. These negative charges are cancelled out by the absorption of cations from solution. The CEC can be estimated by summation of exchangeable bases (Ca, Mg, Na, K) and exchangeable Al. The neutral (pH 7.00) 1.00 M ammonium acetate (NH₄OAc) extraction is the most widely applied method to estimate the soluble and rapidly exchangeable pools of alkali and alkaline elements in soils. The present protocol is modified from Reeuwijk (2002).

Principle

The soil sample is extracted with a 1 M NH₄OAc solution at pH =7.00. The soil-solution slurry is shaken for 2 h, and the solution is separated from the solid by centrifugation. The addition of NH₄⁺ in excess to the soil displaces the rapid exchangeable alkali and alkaline cations from the exchange sites of the soil particles. The concentrations of Na, K, Ca and Mg are subsequently analysed by ICP-OES.

Protocol

Extraction:

1. Transfer 2.0 g air-dried fine soil (<2mm) into 50 ml centrifuge tubes. Include two blanks. Register sample weight (resolution 0.001 g)
2. Add 20 ml 1 M NH₄OAc and fasten the screw cap.
3. Place the tubes in the rotor shaker and extract for two hours.
4. Centrifuges the samples for 10 min at 6,000 g (~ 6,000 min⁻¹) or higher. The samples must be clear after centrifugation.

ICP-analysis:

5. Transfer the supernatant into 15 ml sampling tubes. NOTE: It might be necessary to dilute the samples for analysis by ICP-OES.
6. Analyze the samples for Ca, Mg, Na, and K by ICP-OES.
7. Standards and instrument blanks must be prepared in 1 M NH₄OAc (or if samples are diluted, use the same dilution for standards and instrument blanks).
Calculations

NOTE: Conventionally the unit me/100 g (milliequivalent per 100 g) has been used in soil science. The SI-unit cmol/kg is however used here rather than mmol/kg to facility direct comparison with old data, as 1 me/100 g = 1 cmolc/kg = 1 mmolc/100 g = 10 mmolc/kg. The notation mmolc means mmol of charge.

Exchangeable bases:

\[
\begin{align*}
\text{Exch. Ca} &= \frac{(a - b) \times 20 \times \text{mcf}}{10 \times 20.04 \times s} \quad [\text{cmolc/kg soil DW}] \\
\text{Exch. Mg} &= \frac{(a - b) \times 20 \times \text{mcf}}{10 \times 12.15 \times s} \quad [\text{cmolc/kg soil DW}] \\
\text{Exch. K} &= \frac{(a - b) \times 20 \times \text{mcf}}{10 \times 39.10 \times s} \quad [\text{cmolc/kg soil DW}] \\
\text{Exch. Na} &= \frac{(a - b) \times 20 \times \text{mcf}}{10 \times 23.00 \times s} \quad [\text{cmolc/kg soil DW}]
\end{align*}
\]

where: \(a\) = mg/l Ca, Mg, K or Na in the extraction solution
\(b\) = ditto in the blanks
\(s\) = air-dry sample weight in gram
\(\text{mcf}\) = moisture correction factor
\(20\) = ml of NH₄OAc used in extraction
(The atomic weights of the elements are \(\text{Ca} = 40.078\); \(\text{Mg} = 24.305\);
\(\text{K} = 39.098\); \(\text{Na} = 24.305\))

The ‘effective CEC’ (cation exchange capacity):

\[
\text{ECEC} = \frac{\text{Exch. (Na + K + Ca + Mg + acidity)}}{[\text{cmolc/kg soil DW}]}
\]

Note: See separate protocol for determination of exchangeable acidity
Base saturation:

\[ \text{Base saturation} = \left( \frac{\text{Exch. (Ca + Mg + K + Na)}}{\text{ECEC}} \right) \times 100 \% \]

Materials and reagents

- Scale (resolution 0.001 g)
- Centrifuge tubes, 50 ml, with screw caps (OBS: acid washed)
- 1 M NH₄OAc (CH₃COONH₄). Dissolve 375 g NH₄OAc in distilled water and make up to 5 liter. Adjust pH to 7.00 with ammonia 1M or acetic acid 10%.
- Rotor shaker
- Centrifuge, 6,000 g or higher (Sigma 3-18 K; rotor 12156-H)
- Sample tubes, 15 ml
- Calcium (Ca), magnesium (Mg), potassium (K) and sodium (Na) standards 1000 mg/l; Titrisol to ICP-OES
- ICP-OES

Safety

- No extraordinary safety requirements

Interpretation of soil exchangeable bases and cation exchange capacity:

**CEC**: Cation exchange capacity is the capacity of a soil for ion exchange of positively charged ions between the soil and the soil solution. Cation exchange capacity is used as a measure of fertility, nutrient retention capacity, and the capacity to protect groundwater from cation contamination. CEC varies according to the type of soil. Humus, the end product of decomposed organic matter, has the highest CEC value because organic matter colloids have large quantities of negative charges. Clay has a great capacity to attract and hold cations because of its chemical structure. However, CEC varies according to the type of clay. It is highest in montmorillonite clay, found in chocolate soils and black puggy alluvials. It is lowest in heavily weathered kaolinite clay, found in krasnozem soils, and slightly higher in the less weathered illite clay. Humus has a CEC two to five times greater than montmorillonite clay and up to 30 times greater than kaolinite clay. Sand has no capacity to exchange cations because it has no electrical charge. This means sandy soils such as podzolic topsoils have very low CEC. When exchangeable sodium is present in quantities greater than about 5% of the CEC, it makes the clay particles unstable in...
rainwater. This shows up as dispersion or cloudiness in water. Dispersive soils have poor water entry and drainage and set hard on drying.

**Base-saturation:** Closely related to CEC is the base saturation, which is the fraction of exchangeable cations that are base cations (Ca, Mg, K and Na). The higher the amount of exchangeable base cations, the more acidity can be neutralised in the short time perspective. Thus, a site with high CEC takes longer time to acidify (as well as to recover from an acidified status) than a site with a low CEC (assuming similar base saturations).

<table>
<thead>
<tr>
<th>Soil type</th>
<th>CEC (cmol./kg DW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light colored sands</td>
<td>3-5</td>
</tr>
<tr>
<td>Dark colored sands</td>
<td>10-20</td>
</tr>
<tr>
<td>Light colored loams and silt loams</td>
<td>10-20</td>
</tr>
<tr>
<td>Dark colored silty clay</td>
<td>15-25</td>
</tr>
<tr>
<td>Loams and silty clays</td>
<td>30-40</td>
</tr>
<tr>
<td>Organic soils</td>
<td>50-100</td>
</tr>
</tbody>
</table>

**Table 2.**

Approximate base saturation for kaolinitic soils

<table>
<thead>
<tr>
<th>Soil pH</th>
<th>Base saturation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.9</td>
<td>0</td>
</tr>
<tr>
<td>4.5</td>
<td>0</td>
</tr>
<tr>
<td>5.3</td>
<td>25</td>
</tr>
<tr>
<td>6.2</td>
<td>50</td>
</tr>
<tr>
<td>7.1</td>
<td>75</td>
</tr>
<tr>
<td>7.5</td>
<td>90</td>
</tr>
<tr>
<td>8.0</td>
<td>100</td>
</tr>
</tbody>
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**Reference:**