



Environmental Analysis Program

Pomona College
Biogeochemistry Laboratory

SOP-L416

Cation Exchange Capacity (CEC)

Standard Operating Procedure

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1. Purpose

This SOP describes the determination of cation exchange capacity (CEC) and exchangeable base cations (Ca^{2+} , Mg^{2+} , K^{+} , Na^{+}) in soils using the ammonium acetate (NH_4OAc) saturation and displacement method at pH 7.0 (Chapman, 1965; Sumner & Miller, 1996). CEC quantifies the total capacity of a soil to hold exchangeable cations and is a fundamental indicator of soil fertility, buffering capacity, and nutrient retention (Sparks, 2003).

2. Scope

- **Applies to:** Air-dried, sieved (< 2 mm) mineral soils from all EA Program sites. The method is also applicable to compost and organic amendments, although CEC values for highly organic materials should be interpreted with caution due to pH-dependent charge (Sumner & Miller, 1996).
- **Does not apply to:** Soils dominated by variable-charge minerals (e.g., highly weathered Oxisols, Andisols) where CEC measured at pH 7.0 may overestimate field-effective CEC. For such soils, a compulsive exchange method at field pH may be more appropriate (Gillman & Sumpter, 1979). Does not apply to water samples.
- **Location:** EA Program laboratory, SGM 133

3. Responsibilities

Role	Responsibility
Lab PI	Approve SOP, ensure training compliance
Trained Personnel	Prepare extracts, record and report results
New Students	Complete training before independent use

3.1. Required Training

Students using this SOP should be trained on:

- [SOP-L002 Laboratory Safety](#)
- [SOP-L400 Soil Moisture](#)

4. Definitions

- **Buffered salt solution:** A reagent at a defined pH used to saturate exchange sites with a known index cation (e.g., NH_4^+ at pH 7.0 in the ammonium acetate method); the buffer pH controls which exchange sites are measured.
- **Base saturation:** The percentage of CEC occupied by base cations (Ca^{2+} , Mg^{2+} , K^+ , Na^+); calculated as the sum of base cations divided by CEC, expressed as %; important for liming and fertility management.
- **Cation exchange capacity (CEC):** The total capacity of a soil to hold exchangeable cations, expressed in $\text{cmol}_c \text{ kg}^{-1}$ (or $\text{meq } 100 \text{ g}^{-1}$); governed by clay mineralogy and organic matter content; the higher the CEC, the greater the soil's buffering capacity against acidification and nutrient leaching.
- **Effective CEC (ECEC):** CEC measured at the soil's natural pH (using an unbuffered salt such as 1 M KCl or BaCl_2); represents the actual exchange capacity at field conditions; lower than pH 7-buffered CEC in acid soils.
- **Exchange sites:** Negatively charged surfaces on clay minerals and organic matter that hold cations electrostatically; released by displacing the sorbed cations with a high-concentration competing ion.
- **Index cation:** The cation used to saturate exchange sites before measurement (e.g., NH_4^+ in the ammonium acetate method, Ba^{2+} in the compulsive exchange method); subsequently displaced and quantified to calculate CEC.

5. Safety and Hazards

Hazards

- **Chemical:** 1 M ammonium acetate (NH_4OAc) is a mild irritant. Concentrated acetic acid used in reagent preparation is corrosive and produces irritating vapors. Concentrated ammonium hydroxide (NH_4OH) used for pH adjustment is caustic and produces strong vapors. Ethanol (95%) is flammable.
- **Physical:** Reciprocating shaker can pinch fingers if containers are not secured properly.

Engineering Controls

Prepare 1 M NH_4OAc from concentrated reagents inside a chemical fume hood. Once diluted to working concentration, the solution can be used on the open bench.

5.1. Required PPE

- ☐ Safety glasses or chemical splash goggles (goggles when preparing reagents)
- ☐ Laboratory coat
- ☐ Nitrile gloves
- ☐ Closed-toed shoes

5.2. Emergency Procedures

For chemical spill or splash, refer to [SOP-L002 Laboratory Safety](#) or call campus safety. For acetic acid or ammonium hydroxide contact with eyes, flush immediately with water for at least 15 minutes.

6. Equipment and Materials

6.1. Equipment

Item	Notes
Reciprocating or end-over-end shaker	For batch extraction
Centrifuge	Capable of 2,000–3,000 x g
Vacuum filtration apparatus	Buchner funnel, flask, and vacuum source
Analytical balance	Readable to 0.01 g
Drying oven	105 °C for moisture subsamples
pH meter	For adjusting NH_4OAc to pH 7.0
Volumetric flasks	1 L and 250 mL

6.2. Reagents and Consumables

Item	Notes
Ammonium acetate (NH_4OAc)	ACS reagent grade; or prepare from glacial acetic acid + NH_4OH
Ethanol (95%)	Reagent grade, to wash excess NH_4^+
Potassium chloride (KCl), 2 M	Or 10% NaCl; for displacing adsorbed NH_4^+
Whatman #42 filter paper	Or equivalent, for filtration
Centrifuge tubes (50 mL)	Polypropylene
Volumetric flasks (250 mL)	For collecting leachates
DI water	

7. Procedure

7.1. Reagent Preparation

7.1.1. M Ammonium Acetate (pH 7.0)

1. In a fume hood, dissolve 77.08 g of ammonium acetate ($\text{NH}_4\text{C}_2\text{H}_3\text{O}_2$, MW 77.08) in approximately 800 mL of DI water in a 1 L volumetric flask.
2. Adjust to pH 7.0 using dilute acetic acid (to lower pH) or dilute ammonium hydroxide (to raise pH).
3. Bring to 1 L with DI water and mix thoroughly.

 Tip

Prepare this solution the day before extraction. It is stable indefinitely at room temperature in a capped container. Verify pH before each use, as CO₂ absorption can lower the pH over time.

7.1.2. M Potassium Chloride

Prepare per [SOP-L403, Section 7.1](#).

7.2. Moisture Subsample

A companion gravimetric moisture determination is required to express results on an oven-dry soil basis.

1. Set aside approximately 10 g of soil from each sample for moisture determination
2. Dry at 105 °C for 24 hours and record the dry weight
3. Calculate gravimetric moisture content per [SOP-L400 Soil Moisture](#)

7.3. Ammonium Acetate Saturation (Exchangeable Cations)

1. Weigh 5.00 g of air-dried, sieved (< 2 mm) soil into a labeled 50 mL centrifuge tube. Record the exact mass to 0.01 g.
2. Add 30 mL of 1 M NH₄OAc (pH 7.0) to the tube. Cap securely.
3. Place on the reciprocating shaker for 30 minutes.
4. Centrifuge at 2,000–3,000 x g for 5 minutes. Decant the clear supernatant into a 250 mL volumetric flask. Retain the soil pellet.
5. Repeat steps 2–4 two additional times (three extractions total), combining all supernatants in the same 250 mL volumetric flask.
6. Bring the combined extract to 250 mL with 1 M NH₄OAc and mix. This extract is used for exchangeable cation analysis (Ca²⁺, Mg²⁺, K⁺, Na⁺) by ICP-OES, AAS, or flame photometry (Helmke & Sparks, 1996).

7.4. Ethanol Wash

The ethanol wash removes excess (non-exchanged) NH₄⁺ from the soil without displacing adsorbed NH₄⁺ (Sumner & Miller, 1996).

1. Add 30 mL of 95% ethanol to the soil pellet remaining in the centrifuge tube. Cap and shake for 5 minutes.
2. Centrifuge at 2,000–3,000 x g for 5 minutes. Discard the supernatant ethanol wash.

3. Repeat the ethanol wash two additional times (three washes total).

! Critical Step

Incomplete removal of excess NH_4OAc will cause CEC to be overestimated. Ensure three full ethanol washes with clear supernatant before proceeding.

7.5. Displacement of Adsorbed NH_4^+ (CEC Determination)

1. Add 30 mL of 2 M KCl to the washed soil pellet. Cap and shake for 30 minutes.
2. Centrifuge at 2,000–3,000 x g for 5 minutes. Decant the supernatant into a clean 250 mL volumetric flask.
3. Repeat steps 1–2 two additional times (three displacements total), combining all supernatants in the same flask.
4. Bring the combined KCl extract to 250 mL with 2 M KCl and mix.
5. Determine the NH_4^+ -N concentration in this extract by colorimetric analysis (indophenol blue method), flow injection, or steam distillation (Mulvaney, 1996). This value represents the CEC.

7.6. Cleanup

1. Discard spent soil in standard solid waste.
2. Rinse all glassware and centrifuge tubes with DI water.
3. Return reagents to labeled storage areas.

8. Calculations

8.1. Cation Exchange Capacity

$$\text{CEC (cmol}_c\text{/kg)} = \frac{C_{\text{NH}_4} \times V_{\text{KCl}} \times 10^{-3}}{m_{\text{dry}} \times 14.01} \times 100$$

where:

- C_{NH_4} = NH_4^+ -N concentration in the KCl displacement extract (mg N/L)
- V_{KCl} = total volume of combined KCl extract (mL; typically 250 mL)
- m_{dry} = oven-dry equivalent mass of soil (g), calculated as $m_{\text{air-dry}}/(1 + \theta_g)$
- 14.01 = atomic mass of nitrogen (g/mol)
- The factor of 100 converts from mol_c/g to cmol_c/kg

8.2. Exchangeable Cations

Report exchangeable Ca^{2+} , Mg^{2+} , K^{+} , and Na^{+} from the NH_4OAc extract (§6.3) in cmol_c/kg :

$$\text{Exchangeable cation (cmol}_c/\text{kg)} = \frac{C_{\text{cation}} \times V_{\text{extract}} \times \text{valence}}{M_{\text{cation}} \times m_{\text{dry}}} \times \frac{1}{10}$$

where C_{cation} is in mg/L , V_{extract} in mL , M_{cation} is the atomic mass ($\text{Ca} = 40.08$, $\text{Mg} = 24.31$, $\text{K} = 39.10$, $\text{Na} = 22.99$), and valence is 2 for Ca and Mg and 1 for K and Na .

8.3. Base Saturation

$$\text{Base Saturation (\%)} = \frac{\text{Ca}^{2+} + \text{Mg}^{2+} + \text{K}^{+} + \text{Na}^{+}}{\text{CEC}} \times 100$$

where all values are in cmol_c/kg .

8.4. Interpretation

CEC (cmol_c/kg)	Classification	Typical Soil Textures
< 5	Very low	Sands, degraded tropicals
5–15	Low	Sandy loams, kaolinitic clays
15–25	Medium	Loams, silt loams
25–40	High	Clay loams, smectitic soils
> 40	Very high	Heavy clays, organic soils

Source: adapted from Sparks (2003) and Brady & Weil (2008).

9. Quality Control and Acceptance Criteria

- Include a reagent blank (NH_4OAc and KCl through the full procedure without soil) in each batch. $\text{NH}_4^{+}\text{-N}$ in the blank must be below the method detection limit.
- Run extraction duplicates on at least 10% of samples. Duplicate results should agree within 10% RPD.
- Include a laboratory reference soil with known CEC when available.
- Sum of exchangeable base cations should not exceed CEC. If the sum substantially exceeds CEC, suspect incomplete ethanol washing or analytical error.
- Verify NH_4OAc pH is 7.0 ± 0.05 before each extraction batch.

10. Waste Disposal

Waste Type	Container	Disposal Method
NH ₄ OAc extracts	Drain with water	Low hazard; drain permitted
Ethanol washes	Flammable waste carboy	EH&S pickup
KCl extracts	Drain with water	Low hazard; drain permitted
Spent soil	Standard solid waste	Trash

11. References

- Sumner & Miller (1996)
- Chapman (1965)
- Sparks (2003)
- Helmke & Sparks (1996)
- Mulvaney (1996)
- Gillman & Sumpter (1979)
- Brady & Weil (2008)
- Ross & Ketterings (1995)
- [SOP-L002 Laboratory Safety](#)
- [SOP-L400 Soil Moisture](#)
- [SOP-L403 Nitrate and Ammonium – KCl Extraction](#)

Brady, N. C., & Weil, R. R. (2008). *The nature and properties of soils* (14th ed.). Pearson Prentice Hall.

Chapman, H. D. (1965). Cation-exchange capacity. In C. A. Black (Ed.), *Methods of soil analysis, part 2: Chemical and microbiological properties* (pp. 891–901). American Society of Agronomy. <https://doi.org/10.2134/agronmonogr9.2.c6>

Gillman, G. P., & Sumpter, E. A. (1979). A proposed method for the measurement of exchange properties of highly weathered soils. *Australian Journal of Soil Research*, 17(1), 129–139. <https://doi.org/10.1071/SR9790129>

Helmke, P. A., & Sparks, D. L. (1996). Lithium, sodium, potassium, rubidium, and cesium. In D. L. Sparks, A. L. Page, P. A. Helmke, & R. H. Loeppert (Eds.), *Methods of soil analysis, part 3: Chemical methods* (pp. 551–574). Soil Science Society of America. <https://doi.org/10.2136/sssabookser5.3.c19>

Mulvaney, R. L. (1996). Nitrogen: Inorganic forms. In D. L. Sparks, A. L. Page, P. A. Helmke, & R. H. Loeppert (Eds.), *Methods of soil analysis, part 3: Chemical methods* (pp. 1123–1184). Soil Science Society of America. <https://doi.org/10.2136/sssabookser5.3.c38>

Ross, D. S., & Ketterings, Q. (1995). Recommended methods for determining soil cation exchange capacity. In J. T. Sims & A. Wolf (Eds.), *Recommended soil testing procedures for the north-eastern united states* (3rd ed., pp. 62–69). Northeastern Regional Publication No. 493.

Sparks, D. L. (2003). *Environmental soil chemistry* (2nd ed.). Academic Press. <https://doi.org/10.1016/B978-012656446-4/50001-3>

Sumner, M. E., & Miller, W. P. (1996). Cation exchange capacity and exchange coefficients. In D. L. Sparks, A. L. Page, P. A. Helmke, & R. H. Loeppert (Eds.), *Methods of soil analysis, part 3: Chemical methods* (pp. 1201–1229). Soil Science Society of America. <https://doi.org/10.2136/sssabookser5.3.c40>

12. Training Record

Before performing CEC analysis independently, personnel must:

1. Read this SOP in full
2. Complete [SOP-L002 Laboratory Safety](#) training
3. Review the SDS for ammonium acetate, acetic acid, ammonium hydroxide, and ethanol
4. Complete [SOP-L400 Soil Moisture](#) training
5. Observe a trained operator perform the full extraction sequence
6. Perform the procedure under supervision with acceptable duplicate precision (RPD < 10%)
7. Be signed off by the PI or lab manager

13. Appendix A: Example Calculation

```
# --- CEC Calculation Example ---

# Input values
nh4_mg_L    <- 42.5    # NH4-N in KCl displacement extract (mg/L)
vol_KCl_mL  <- 250     # Total volume of combined KCl extract (mL)
mass_air_g  <- 5.00    # Air-dried soil mass (g)
moisture    <- 0.032   # Gravimetric moisture content (decimal)

# Oven-dry mass
mass_dry_g <- mass_air_g / (1 + moisture)

# CEC in cmol_c/kg
cec <- (nh4_mg_L * vol_KCl_mL * 1e-3) / (mass_dry_g * 14.01) * 100

cat(sprintf("Oven-dry soil mass: %.3f g\n", mass_dry_g))
cat(sprintf("CEC: %.1f cmol_c/kg\n", cec))

# --- Exchangeable Cation Example (Ca from NH4OAc extract) ---
ca_mg_L     <- 85.2    # Ca concentration in NH4OAc extract (mg/L)
vol_ext_mL  <- 250     # Total volume of NH4OAc extract (mL)
ca_mw       <- 40.08   # Atomic mass of Ca
ca_valence  <- 2

exch_ca <- (ca_mg_L * vol_ext_mL * ca_valence) / (ca_mw * mass_dry_g) / 10

cat(sprintf("Exchangeable Ca: %.1f cmol_c/kg\n", exch_ca))
```