



Environmental Analysis Program

Pomona College
Biogeochemistry Laboratory

SOP-L403

Soil Nitrate and Ammonium – KCl Extraction

Standard Operating Procedure

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1. Purpose

This SOP describes the extraction of inorganic nitrogen (nitrate, NO_3^- , and ammonium, NH_4^+) from soil using 2 M potassium chloride (KCl). The KCl extraction is the standard method for determining plant-available inorganic nitrogen in soils (Keeney & Nelson, 1982; Mulvaney, 1996). The high ionic strength of the KCl solution displaces NH_4^+ from cation exchange sites and brings NO_3^- into solution, producing a filtered extract suitable for colorimetric, flow-injection, or ion chromatographic analysis (Maynard et al., 2008).

2. Scope

- **Applies to:** Field-moist or air-dried soil samples collected per [SOP-F400 Soil Sampling and Processing](#)
- **Does not apply to:** Total nitrogen analysis (requires Kjeldahl or combustion digestion; see [SOP-L407](#)); dissolved nitrogen in water samples; semi-quantitative field screening (see [SOP-L404](#))
- **Location:** EA Program laboratory, SGM 133

3. Responsibilities

Role	Responsibility
Lab PI	Approve protocol, 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-F001 Field Safety](#)
- [SOP-L003 Hazardous Materials Handling](#)
- [SOP-L400 Soil Moisture](#)

4. Definitions

- **Ammonium (NH_4^+):** The protonated form of ammonia; held on negatively charged cation exchange sites in soil; released into solution by the high ionic strength of the 2 M KCl extractant; the primary plant-available nitrogen pool in many soils.
- **Cation exchange capacity (CEC):** The total capacity of a soil to hold exchangeable positively charged ions; controls how much NH_4^+ can be stored and released; higher in clay-rich and organic-matter-rich soils.
- **KCl extraction:** Shaking soil with 2 mol L⁻¹ potassium chloride solution at a defined soil-to-solution ratio (typically 1:10 w/v); the standard procedure for quantifying plant-available inorganic nitrogen in soils (Keeney & Nelson, 1982).
- **Mineral nitrogen (mineral N):** The sum of NH_4^+ -N and NO_3^- -N in the soil; the immediately plant-available nitrogen pool; expressed in mg N kg⁻¹ dry soil.
- **Nitrate (NO_3^-):** The oxidized form of inorganic nitrogen; anion, so not held on cation exchange sites; highly mobile in soil solution; measured colorimetrically or by flow injection analysis after KCl extraction.
- **Soil-to-solution ratio:** The mass of soil (g) to volume of extractant (mL) used in the extraction; typically 1:10 for KCl extractions; must be consistent within and between studies for results to be comparable.

5. Safety and Hazards

Hazards

- **Chemical:** 2 M KCl is a mild irritant; avoid contact with eyes and skin. Review the SDS before first use.
- **Physical:** Reciprocating shaker can pinch fingers if containers are not secured properly.

5.1. Required PPE

- ☐ Nitrile gloves
- ☐ Safety glasses
- ☐ Lab coat
- ☐ Closed-toed shoes

6. Required Materials

6.1. Equipment

Item	Notes
Reciprocating shaker	For 2-hour extraction (Keeney & Nelson, 1982)
Magnetic stirrer with stir bar	For preparing KCl solution
Stir bar retriever	Magnetic wand

Item	Notes
Top-loading balance	0.1 g resolution
Graduated cylinder or volumetric flask	2 L capacity for KCl preparation
Repipet-type dispenser	For dispensing KCl solution (optional)
Drying oven	Set to 105 C (for moisture subsample)
Sorvall ST8R Centrifuge	Optional; see SOP-L109

6.2. Consumables

Item	Cat. No.	Notes
Whatman #42 filter paper		Ashless, 185 mm diameter
Filter funnels	09-855F	To fit filter paper
Test tubes or extraction bottles	S89476	50 mL capacity, with caps
Specimen containers or Nalgene bottles		For collecting filtered extracts
Aluminum weigh boats		For moisture subsamples
Pipette		For dispensing precise volumes

6.3. Reagents

Item	Cat. No.	Notes
Potassium chloride (KCl)	AA11595A1	ACS grade; 298.2 g per 2 L for 2 M solution
Distilled or deionized water		For preparing KCl solution

7. Estimated Time

Task	Time Required
KCl solution preparation	10 minutes active + 2 hours stirring
Moisture subsamples	5 minutes active + 24 hours drying
KCl extraction (per batch)	15 minutes setup + 2 hours shaking + 10 minutes settling
Filtering	20–30 minutes per batch

8. Procedure

8.1. Preparing 2 M KCl Solution

The 2 M KCl concentration is the standard for inorganic N extraction (Keeney & Nelson, 1982; Mulvaney, 1996). Lower concentrations (e.g., 1 M) may underestimate exchangeable NH_4^+ in

high-CEC soils (Maynard et al., 2008).

1. Weigh out 298.2 g KCl into a 2 L volumetric flask
2. Fill the flask approximately two-thirds full with distilled water
3. Place the flask on a magnetic stirrer and add a magnetic stir bar
4. Set the stirrer to low-medium speed and leave on for 4 hours until fully dissolved
5. Use a stir bar retriever to remove the magnetic stir bar
6. Fill the flask to the 2 L mark with distilled water and mix

Tip

Prepare the KCl solution the day before extraction. It can be stored at room temperature in a capped container indefinitely. Verify the solution with a conductivity meter if stored for more than 6 months.

8.2. Moisture Subsample

A companion gravimetric moisture determination is required to express results on an oven-dry soil basis (Keeney & Nelson, 1982).

1. Set aside 10 g of soil from each sample for moisture determination
2. Place each 10 g subsample into a labeled aluminum weigh boat
3. Dry at 105 C for 24 hours and record the dry weight
4. Calculate gravimetric moisture content per [SOP-L400 Soil Moisture](#)

8.3. KCl Extraction

The standard soil-to-solution ratio is approximately 1:5 to 1:10 (w/v) (Mulvaney, 1996). This SOP uses 7 g field-moist soil in 40 mL KCl, yielding an effective ratio of approximately 1:6 on an oven-dry basis for a typical soil at 15% gravimetric moisture.

1. Dispense 40 mL of 2 M KCl solution into labeled test tubes or extraction bottles
2. Add 7 g of field-moist soil to each tube (the total volume should reach approximately 50 mL). Record the exact mass of soil added to the nearest 0.01 g.
3. Cap the tubes securely
4. Place on the reciprocating shaker for 2 hours
5. Remove from the shaker and either:
 - Allow soil particles to settle for approximately 10 minutes (do not exceed 1 hour), or
 - Centrifuge for 3 minutes at 9,000 rpm (see [SOP-L109: Sorvall ST8R Centrifuge](#))

Important

Record the exact mass of field-moist soil added to each tube. This value, together with the gravimetric moisture content, is needed to calculate results on an oven-dry basis (see Appendix

A).

8.4. Filtering

1. Set up filter funnels with Whatman #42 filter paper over labeled specimen containers or clean test tubes
2. Pour the settled or centrifuged solution into the funnels; do not fill above the filter paper line
3. Allow the solution to drain completely until only soil remains on the filter
4. Discard the used filter paper and soil

8.5. Extract Storage

1. Cap the filtered extract containers
2. If analysis will be completed within 48 hours, store at 4 C
3. If analysis will be delayed beyond 48 hours, freeze the extracts at -20 C until analysis (Keeney & Nelson, 1982)

! Important

Extracts should be analyzed as soon as possible. Prolonged storage, even frozen, can alter NH_4^+ and NO_3^- concentrations due to microbial activity or chemical transformations (Maynard et al., 2008).

9. Calculations

9.1. Converting Extract Concentration to Soil Concentration

The colorimetric or flow-injection analyzer reports the concentration of NO_3^- -N or NH_4^+ -N in the filtered extract (mg N/L). To convert this to mg N per kg oven-dry soil (ppm):

$$C_{\text{soil}} (\text{mg N kg}^{-1}) = \frac{C_{\text{extract}} \times V_{\text{KCl}}}{m_{\text{dry}}}$$

where:

- C_{extract} = concentration in the filtered extract (mg N/L)
- V_{KCl} = volume of KCl extractant added (L; typically 0.040 L)
- m_{dry} = oven-dry equivalent mass of soil extracted (kg), calculated as:

$$m_{\text{dry}} = \frac{m_{\text{moist}}}{1 + \theta_g}$$

where m_{moist} is the field-moist mass added (g, converted to kg) and θ_g is the gravimetric moisture content expressed as a decimal (g water / g oven-dry soil).

See Appendix A for a worked R code example.

9.2. Soil Texture Correction Factor (Optional)

When using the semi-quantitative quick test (SOP-L404), a texture-based correction factor may be applied. For the quantitative KCl extraction described here, no texture correction is needed because the exact soil mass and moisture content are measured directly.

Texture	Moist Soil Factor	Dry Soil Factor
Sand	2.3	2.6
Loam	2.0	2.5
Clay	1.7	2.2

These factors are retained here for reference when comparing quick-test results to KCl extraction results.

10. Quality Control

- Include a reagent blank (KCl solution only, no soil) in each extraction batch. The blank should read below the method detection limit for both NO_3^- -N and NH_4^+ -N.
- Run extraction duplicates for at least 10% of samples. Duplicate results should agree within 15% relative percent difference (RPD).
- Include a laboratory reference soil with known inorganic N content in each batch when available.
- Record the KCl solution preparation date and batch number.
- Verify that the analytical calibration curve for the colorimetric method has an $r^2 \geq 0.995$ before reporting results.
- Subtract the mean reagent blank concentration from all sample results if the blank reads above zero (Mulvaney, 1996).

11. Waste Disposal

Waste Type	Disposal Method
KCl extracts	Aqueous waste; drain with copious water if approved by EH&S, or collect for pickup
Used filter paper and soil	Standard trash
Unused KCl solution	Drain with water (non-hazardous at this concentration)

12. References

Hart, S. C., Stark, J. M., Davidson, E. A., & Firestone, M. K. (1994). Nitrogen mineralization, immobilization, and nitrification. In R. W. Weaver, J. S. Angle, & P. S. Bottomley (Eds.), *Methods of soil analysis, part 2: Microbiological and biochemical properties* (pp. 985–1018). Soil Science Society of America. <https://doi.org/10.2136/sssabookser5.2.c42>

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- 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>

13. Training Record

Before performing this procedure independently, personnel must:

1. Read this SOP in full
2. Complete [SOP-L400 Soil Moisture](#) training
3. Demonstrate competence preparing KCl solution
4. Perform the extraction and filtering procedure under supervision
5. Calculate results for one batch using the R code in Appendix A and verify against the instructor's values
6. Be signed off by the PI or lab manager

14. Appendix A: Calculation of Soil NO_3^- -N and NH_4^+ -N (R Code)

The following R code converts extract concentrations (mg N/L from the colorimetric analyzer) to soil concentrations (mg N/kg oven-dry soil, equivalent to ppm) for a batch of samples. It corrects for the exact mass of field-moist soil added and the gravimetric moisture content of each sample.

```
# =====  
# SOP-L403: KCl Extraction -- Convert extract concentration to soil ppm  
# =====  
  
# ---- 1. Enter your data -----  
# Replace the example values below with your actual data.  
# Each vector must have the same length (one entry per sample).  
  
sample_id <- c("S01", "S02", "S03", "S04", "S05")  
  
# Mass of field-moist soil added to the extraction tube (g)  
soil_moist_g <- c(7.03, 7.10, 6.98, 7.05, 7.12)  
  
# Gravimetric moisture content (proportion, g water / g oven-dry soil)
```

```
# From SOP-L400. Example: 0.15 means 15% moisture.
theta_g <- c(0.152, 0.148, 0.161, 0.155, 0.143)

# Volume of 2 M KCl added (mL) -- typically 40 mL for all samples
vol_kcl_mL <- rep(40, length(sample_id))

# Extract concentrations from the colorimetric analyzer (mg N / L)
no3_extract_mg_L <- c(3.42, 5.18, 2.76, 4.01, 6.33)
nh4_extract_mg_L <- c(1.05, 0.87, 1.22, 0.93, 0.78)

# Reagent blank concentrations (mg N / L) -- mean of your blanks
blank_no3_mg_L <- 0.02
blank_nh4_mg_L <- 0.01

# ---- 2. Calculate oven-dry soil mass (kg) -----
soil_dry_g <- soil_moist_g / (1 + theta_g)
soil_dry_kg <- soil_dry_g / 1000

# ---- 3. Blank-correct extract concentrations -----
no3_corrected <- no3_extract_mg_L - blank_no3_mg_L
nh4_corrected <- nh4_extract_mg_L - blank_nh4_mg_L

# Ensure no negative values after blank correction
no3_corrected[no3_corrected < 0] <- 0
nh4_corrected[nh4_corrected < 0] <- 0

# ---- 4. Convert to mg N / kg oven-dry soil (ppm) -----
vol_kcl_L <- vol_kcl_mL / 1000

no3_ppm <- (no3_corrected * vol_kcl_L) / soil_dry_kg
nh4_ppm <- (nh4_corrected * vol_kcl_L) / soil_dry_kg

# ---- 5. Assemble results table -----
results <- data.frame(
  Sample      = sample_id,
  Moist_g     = soil_moist_g,
  Moisture_pct = round(theta_g * 100, 1),
  Dry_g       = round(soil_dry_g, 3),
  Vol_KCl_mL  = vol_kcl_mL,
  NO3_extract = no3_extract_mg_L,
  NH4_extract = nh4_extract_mg_L,
  NO3_ppm     = round(no3_ppm, 2),
  NH4_ppm     = round(nh4_ppm, 2),
  Total_inorgN = round(no3_ppm + nh4_ppm, 2)
)

# ---- 6. Print results -----
```

```
cat("SOP-L403: KCl Extraction Results\n")
cat("=====\n\n")
print(results, row.names = FALSE)
cat("\n")
cat(sprintf("Reagent blank NO3-N: %.2f mg/L\n", blank_no3_mg_L))
cat(sprintf("Reagent blank NH4-N: %.2f mg/L\n", blank_nh4_mg_L))
cat("\nAll soil concentrations are mg N / kg oven-dry soil (ppm).\n")
```

14.1. Worked Example (Sample S01)

Using the example data above for sample S01:

- Field-moist soil added: 7.03 g
- Gravimetric moisture: 15.2% (0.152)
- Oven-dry equivalent: $7.03 / (1 + 0.152) = 6.102 \text{ g} = 0.006102 \text{ kg}$
- KCl volume: 40 mL = 0.040 L
- NO_3^- -N in extract: 3.42 mg/L (blank-corrected: 3.40 mg/L)
- Soil NO_3^- -N: $(3.40 \times 0.040) / 0.006102 = 22.29 \text{ mg N/kg (ppm)}$
- NH_4^+ -N in extract: 1.05 mg/L (blank-corrected: 1.04 mg/L)
- Soil NH_4^+ -N: $(1.04 \times 0.040) / 0.006102 = 6.82 \text{ mg N/kg (ppm)}$
- Total inorganic N: $22.29 + 6.82 = 29.11 \text{ mg N/kg (ppm)}$

15. Appendix B: Interpretation Guide

General interpretation thresholds for extractable inorganic N in agricultural and wildland soils. These are approximate and vary by crop, climate, and soil type (Hart et al., 1994; Mulvaney, 1996).

Extractable Inorganic N (mg N/kg)	Interpretation	Notes
Less than 10	Low	Nitrogen likely limiting plant growth
10–25	Moderate	Adequate for many crops and native vegetation
25–50	High	Sufficient N; fertilization generally not needed
Greater than 50	Very high	Excess N; potential leaching or denitrification concern