Crops Access More Potassium Than Is in a Soil Test

T. Scott Murrell
Potassium Program Director, IPNI

2017 Indiana CCA Conference, Indianapolis, IN.
Outline

I. Minerals with potassium (K) that is not detected by standard soil tests

II. What a standard K soil test measures

III. How plants access more K than is in a soil test
   A. Create concentration gradients in the rhizosphere
   B. Exude H\(^+\) and organic acids into the rhizosphere
   C. Form symbiotic relationships with microbial communities in the rhizosphere
Phyllosilicates: Layer Structure

Basic Phyllosilicate Types

Kaolinite

**PLANES OF IONS**
- basal O’s →
- tetrahedral cations →
- OH’s & apical O’s →
- octahedral cations →
- OH’s →

**SHEETS, LAYERS**
- tetrahedral sheet
- octahedral sheet

Mica Weathers to Other 2:1 Minerals

# Major 2:1 Phyllosilicate Minerals with Interlayer K

<table>
<thead>
<tr>
<th>Relative degree of soil development</th>
<th>Ideal mineral</th>
<th>Interlayer distance</th>
<th>Layer charge</th>
<th>Interlayer K hydration?</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Mica: Biotite</td>
<td>1</td>
<td>1</td>
<td>no</td>
</tr>
<tr>
<td>4</td>
<td>Mica: Phlogopite</td>
<td>1</td>
<td>1</td>
<td>no</td>
</tr>
<tr>
<td>7</td>
<td>Mica: Muscovite</td>
<td>1</td>
<td>1</td>
<td>no</td>
</tr>
<tr>
<td>7</td>
<td>Illite</td>
<td>1</td>
<td>0.6 – 0.8</td>
<td>no</td>
</tr>
<tr>
<td>8</td>
<td>Vermiculite</td>
<td>1.4</td>
<td>0.6 – 0.9</td>
<td>yes</td>
</tr>
<tr>
<td>9</td>
<td>Smectite</td>
<td>1.2 – 1.5</td>
<td>0.2 – 0.6</td>
<td>yes</td>
</tr>
</tbody>
</table>


Tectosilicates (Feldspars)

- Made up of tetrahedra with one silicon surrounded by four oxygens
- Potassium in the structure balances negative charges in the structure and is bound more loosely than silicon and oxygen

II. What a Standard Potassium Soil Test Measures
Ammonium Acetate and Mehlich III Extractants

Hydrated ions:
- Na$^+$
- K$^+$
- NH$_4^+$
- Mg$^{2+}$
- Ca$^{2+}$

Mehlich, 1985; Warnke and Brown, 1998
There Are Conditions where Soil Tests Can Quantify Most of the K Plants Access

- Study located in north Florida
- Corn grown under pivot irrigation
- Orangeburg loamy fine sand (Fine-loamy, kaolinitic, thermic Typic Kandiudult)
  - Ultisol: low supply of basic cations
  - Kandic horizon: low activity clay from 7 to 72 inches, composed mainly of 1:1 layer silicate clays with a lower CEC
  - Kaolinitic: more than 50% kaolinite

There Are Conditions where Soil Tests Can Quantify Most of the K Plants Access

\[ K \text{ uptake} = 91.2 \times \ln(\text{soil test K}) - 306 \]
\[ R^2 = 0.62 \]

Example of a Location Where Lower Soil Tests Are Associated with Lower Yields

![Graph showing the relationship between relative corn yield and K_{exch} (mg kg^{-1}).](image)

- Linear-plateau model
- 95% confidence band
- Plateau K_{exch}
- Critical K_{exch} range
- Mean relative yield

R.Navarette-Gonchozo. 2013. Personal communication (Purdue University)
Example of a Location Where Lower Soil Tests Are Not Associated With Lower Yields

![Graph showing the relationship between relative corn yield and K_{exch} (mg kg^{-1}).](image)
III. How Plants Access More K Than Is in a Soil Test
Visualization of Rhizosphere Volume Using Radioactive $^{86}$Rb and X-Ray Film

Photograph of roots

Overview of Ways Plants Access Potassium in the Rhizosphere

The diagram illustrates how plants access potassium in the rhizosphere. Bacteria in the rhizosphere release organic acids and other C compounds, which facilitate the uptake of K. The release of H+ ions helps in the mobilization of K from the soil. The concentration of K increases in the rhizosphere, indicating a higher availability of this nutrient for plant uptake.
III. How Plants Access More K Than Is in a Soil Test

A. Create concentration gradients in the rhizosphere
Depletion of K in the Rhizosphere
(Oilseed rape after 7 days)

S.A. Barber (1995): 2-5 mg K L\(^{-1}\) was the most observed soil solution K concentration range for 142 U.S. Midwestern soils.
Root-Induced Mineral Transformations in the Rhizosphere

<table>
<thead>
<tr>
<th>Starting mineral</th>
<th>Ending mineral</th>
<th>Crop</th>
<th>Duration</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>mica: biotite</td>
<td>vermiculite</td>
<td>wheat</td>
<td>1 year</td>
<td>Mortland et al., 1956</td>
</tr>
<tr>
<td>mica: phlogopite</td>
<td>vermiculite</td>
<td>ryegrass</td>
<td>4 days</td>
<td>Hinsinger et al., 1992</td>
</tr>
<tr>
<td>mica: phlogopite</td>
<td>vermiculite</td>
<td>ryegrass</td>
<td>32 days</td>
<td>Hinsinger and Jaillard, 1993</td>
</tr>
<tr>
<td>mica: phlogopite</td>
<td>hydroxy-interlayered vermiculite</td>
<td>rape</td>
<td>32 days</td>
<td>Hinsinger et al., 1993</td>
</tr>
</tbody>
</table>

General mechanism:
Mica – K⁺ movement of hydrated cations in the interlayer = vermiculite

III. How Plants Access More K Than Is in a Soil Test

B. Exude H⁺ and organic acids into the rhizosphere
Proton Pump Aids Transport of Nutrient Ions across the Plasma Membrane

Tectosilicates (Feldspars)

$H^+$ exchanges reversibly with $K^+$ in the feldspar structure, releasing $K^+$ into solution.

Inorganic Acid (H⁺) in the Rhizosphere Can Exchange with Interlayer K

- H⁺ exchanges with some K⁺ from the interlayer
- Remaining K⁺ rearranges from structural “holes” to the water interlayer
- Layers collapse around the new interlayer structure

Organic Acids Release K from Minerals

Available K (ppm)

- 5 mmol L^{-1} Oxalic acid
- 5 mmol L^{-1} Citric acid
- 50 mmol L^{-1} Oxalic acid
- 50 mmol L^{-1} Citric acid

III. How Plants Access More K Than Is in a Soil Test

C. Form symbiotic relationships with microbial communities in the rhizosphere
Rhizodeposition of Carbon Enriches the Rhizosphere

Loss of cells

Loss of root cap and border cells

Loss of soluble exudates

Loss of volatile organic compounds

Loss to symbionts

About 11% of plant carbon is deposited in the rhizosphere

K-Solubilizing Bacteria (KSB)

- KSB have been isolated from the rhizospheres of corn, banana, sugarcane, potato, pigeon pea, tobacco
- KSB utilize carbon compounds in the rhizosphere
- KSB produce $H^+$ and organic acids that break down mineral structures

Paenibacillus mucilaginosus
https://spacemicrobes.org/baseball_cards/paenibacillus-mucilaginosus/

K-Solubilizing Bacteria (KSB)

Where to from Here?
New K Recommendations in North Dakota

- Yield response to K was reduced by the presence of K-feldspars
- Soils with more illite had a critical soil test level 50 ppm lower than soils with less illite
How Can Lack of Yield Response on a Sand Be Explained?

![Graph showing the relationship between relative corn yield and K_{exch} (mg kg^{-1}). The graph includes a linear plateau model, 95% confidence band, plateau K_{exch}, critical K_{exch} range, and mean relative yield.](image)

R. Navarette-Gonchozo. 2013. Personal communication (Purdue University)
Fine Sand Particles Can Have Mineral Inclusions

• Fine Sand (100 – 250 μm)
• Individual quartz grains contained inclusions of
  – Feldspar
  – Mica
• May help explain why some sands seem to have an adequate supply of K

The Future

• Improvements in soil test extractants will get us only so far:
  – The sodium tetraphenyl boron test detects interlayer K, but the quantity extracted depends on the reaction time. Matching the results of this test to what a plant accesses will be difficult.
  – Ion exchange resins mimic roots as a “sink” for nutrients, but do not provide microbiomes for bacteria and other microorganisms.

• How well a particular soil test correlates with yield response or nutrient uptake will be highly dependent on the mineral composition of the soil and the hybrids/varieties being grown.