Soil Potassium Dynamics

Jim Friedericks
Outreach & Education Advisor
Potassium dynamics in soil

• Why are these results so different?
  – A 4 year sampling plan
  – Results don’t reflect management practices
  – What’s going on?
Putting Soil Results in Context

Average Soil K test levels

Fifteen years of Iowa samples.
Soil Potassium

http://soiltest.ipni.net/
Soil Potassium
http://soiltest.ipni.net/

An interactive tool for displaying soil nutrient levels across North America over time.

Click the Charts tab to begin exploring the data.

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Soil Potassium

http://soiltest.ipni.net/
Soil Potassium

http://soiltest.ipni.net/
Potassium dynamics in soil

• What influences soil test potassium values?
  – Soil clay structure and cation exchange
  – Soil sampling variability
  – Fertilizer Recommendations
Soil clay has several forms but the 2:1 clays are common in this area.

Derived from minerals rich in potassium, calcium and magnesium.
Clay crystals form in layers

Two layers of silica and one of alumina

- Charges come from substitution of
  - $\text{Al}^{3+}$ for $\text{Si}^{4+}$
  - $\text{Mg}^{2+}$ for $\text{Al}^{3+}$

- These internal charges attract cations (K, Ca, Mg, etc) to the surface
The negative charges in the crystal attract cations to the surface of the clay layer. Variable spacing between the layers depends on the hydration radius of the adsorbed ions.
Clay structures

The negative charges in the crystal are able to attract cations to the surfaces of the clay layers.
Clay structures

Water associated with the cations causes the layers to open up.
Clay types

Unavailable K
(feldspars, micas, etc.)
90-98% of total K

Slowly available K
Non-exchangeable
1-10% of total K

Readily available K
Exchangeable K & K in solution
1-2% of total K

Muscovite Mica

Illite

Smectite or Vermiculite

80-100,000 ppm K

40-60,000 ppm K

<10,000 ppm
Potassium and clays

- Clays are layers of charged particles that absorb cations including K

- Different proportion of K exist in the soil at any one given time
  - Fixed (physically part of the soil composition) (90-95% of total K)
  - Non-exchangeable (slowly exchangeable) (8 – 5 % of total K)
    - Distributed within individual sheets
  - Exchangeable (and solution K) (1-2% of total K)
Clay types

Unavailable K (feldspars, micas, etc.)
90-98% of total K

Slowly available K
Non-exchangeable
1-10% of total K

Readily available K
Exchangeable K & K in solution
1-2% of total K

Muscovite Mica

K-K-K-K

2:1 layer

80-100,000 ppm K

K + HC

Illite

K-K-K

K-K-K

Mica

Core

K

frayed edges

40-60,000 ppm K

Smectite or Vermiculite

K

wedge

Hydrated Exchangeable Cations

<10,000 ppm
Potassium Extraction

Ammonium exchange

Replace all the adsorbed cations with other cations

\[ \text{Ca}^{2+} \quad \text{Mg}^{2+} \quad \text{K}^+ \quad \text{NH}_4^+ \quad \text{NH}_4^+ \]

\[ \text{NH}_4^+ \quad \text{NH}_4^+ \]
Extracting the soil with Ammonium Acetate replaces all the exchangeable cations with NH₄⁺ and the cation concentrations in the extract are determined.
Cation Exchange Capacity

- Typical for Central Iowa:
  - Clay Loams
  - 4 – 6 % OM
  - 6.5 – 7.5 pH

Table 2. Typical cation exchange capacities of soils and soil components.
The CEC of soil is expressed as charges per 100 grams of soil (meq/100g).

<table>
<thead>
<tr>
<th>Material</th>
<th>CEC (meq/100g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay Types</td>
<td></td>
</tr>
<tr>
<td>Kaolinite</td>
<td>3-15</td>
</tr>
<tr>
<td>Illite</td>
<td>15-40</td>
</tr>
<tr>
<td>Montmorillonite</td>
<td>80-100</td>
</tr>
<tr>
<td>Organic Matter</td>
<td>200-400</td>
</tr>
<tr>
<td>Soil Texture</td>
<td></td>
</tr>
<tr>
<td>Sand</td>
<td>1-5</td>
</tr>
<tr>
<td>Fine Sandy Loam</td>
<td>5-10</td>
</tr>
<tr>
<td>Loam</td>
<td>5-15</td>
</tr>
<tr>
<td>Clay Loam</td>
<td>15-30</td>
</tr>
<tr>
<td>Clay</td>
<td>&gt;30</td>
</tr>
</tbody>
</table>
Base Saturation

- Basic cations are determined by extraction with ammonium – either ammonium acetate or Mehlich 3 solution.

- Acidity is determined by the buffer pH and is calculated from an estimate of the CEC.
Base Saturation

Ions adsorbed on clay and humus surfaces are exchangeable and in equilibrium with the soil solution.

The sum of the cations adsorbed on solid surfaces is the cation exchange capacity, CEC.

\[ \text{H}^+ \text{ is acidic, the rest are bases.} \]
## Base Saturation

### Table 1. Example of Base Saturation Calculation

<table>
<thead>
<tr>
<th>Element</th>
<th>K+</th>
<th>Mg++</th>
<th>Ca++</th>
<th>Na+</th>
<th>Base (sum)</th>
<th>Acidity (H+)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hypothetical Soil Test (ppm)</td>
<td>75</td>
<td>150</td>
<td>1800</td>
<td>30</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Divide ppm by this factor to calculate meq/100 g</td>
<td>390</td>
<td>120</td>
<td>200</td>
<td>230</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>meq/100 g</td>
<td>0.19</td>
<td>1.25</td>
<td>9</td>
<td>0.13</td>
<td>10.57</td>
<td>2</td>
<td>12.57</td>
</tr>
<tr>
<td>% of CEC</td>
<td>1.50%</td>
<td>9.90%</td>
<td>71.60%</td>
<td>1.00%</td>
<td>84.10%</td>
<td>15.90%</td>
<td>100.00%</td>
</tr>
</tbody>
</table>

\[
CEC = \frac{K \text{ ppm}}{390} + \frac{Mg \text{ ppm}}{120} + \frac{Ca \text{ ppm}}{200} + \frac{Na \text{ ppm}}{230} + \text{H (buffer pH)}
\]

\[
CEC = \text{Acid (meq/100g)} + \text{Base (meq/100g)}
\]

\[
\text{Base Saturation} = \frac{\text{Base (meq/100g)}}{\text{CEC} \times 100}
\]
Measuring Soil Fertility

• Accuracy – how close to the true value?
  – Degree of variability
  – Bias in all results

• Precision – how repeatable is the result?
  – Uncertainty of result
Variability in a field

Cornfields in Kentucky

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>145</td>
<td>155</td>
<td>180</td>
<td>230</td>
</tr>
<tr>
<td>205</td>
<td>210</td>
<td>230</td>
<td>317</td>
</tr>
<tr>
<td>225</td>
<td>230</td>
<td>250</td>
<td>305</td>
</tr>
<tr>
<td>205</td>
<td>130</td>
<td>166</td>
<td>195</td>
</tr>
<tr>
<td>130</td>
<td>111</td>
<td>120</td>
<td>190</td>
</tr>
</tbody>
</table>

Grid sampled at 0.01 acre (20 ft x 20 ft)  
400 ft²

Found 2 to 3 fold variability in STK

From Steve Philips, IPNI North America.  
http://www.cropnutrition.com/variability-in-soil-test-potassium
How much variability?

Oklahoma pasture

Sampled on one foot grids

490 ft\(^2\)  Approximately 0.01 acre

9 ft\(^2\) is the largest area that had the same K value, Or 3 ft between points with the same K value

How many cores make a good quality sample?

- 22% ----
- 17% ----
- 15 – 23 ppm
- 16 – 22 ppm
- 50%
Soil Variability

- Soil profile variability
  - Requires consistent sampling strategies
  - Is magnified by management practices
STK vs Soil Depth

- Soil test K decreases with depth, with the greatest concentration at the 0-2” depth.
- A composite soil sample 0-6” represents a profile average.
- Crop root density is maximum between 2 and 8 inch depth.
What about yearly variability?

- Why are these results so different?
  - A 4 year sampling plan
  - Results don’t reflect management practices
  - What’s going on?
Putting Soil Results in Context

Average Soil K test levels

Fifteen years of Iowa samples.
Soil Potassium

http://soiltest.ipni.net/

Potassium sample distribution: South Dakota

<table>
<thead>
<tr>
<th>Ammonium acetate equivalent soil test level, ppm</th>
<th>2001; 17,806</th>
<th>2005; 33,730</th>
<th>2010; 67,426</th>
<th>2015; 133,310</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-40</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>41-80</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>81-120</td>
<td></td>
<td></td>
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<tr>
<td>121-160</td>
<td></td>
<td></td>
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<tr>
<td>161-200</td>
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<td></td>
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<tr>
<td>&gt;320</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Making Recommendations

Soil Test Ranges for Potassium

<table>
<thead>
<tr>
<th>Nutrient Level Classification</th>
<th>Soil Test Potassium ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Low</td>
<td>0 - 40</td>
</tr>
<tr>
<td>Low</td>
<td>41 - 80</td>
</tr>
<tr>
<td>Medium / Optimum</td>
<td>81 - 120</td>
</tr>
<tr>
<td>High</td>
<td>121 - 160</td>
</tr>
<tr>
<td>Very High</td>
<td>161+</td>
</tr>
</tbody>
</table>
Making Recommendations

Calibration table for the Soil Test Classifications.

<table>
<thead>
<tr>
<th>Nutrient Level Classification</th>
<th>Probability of seeing response to fertilizer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Low</td>
<td>&gt;80 %</td>
</tr>
<tr>
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<td>High</td>
<td>20 %</td>
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<td>Very High</td>
<td>&lt;20 %</td>
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Making Recommendations

- Potassium recommendations equations

<table>
<thead>
<tr>
<th>Crop</th>
<th>Unit</th>
<th>$K_2O$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>bu</td>
<td>$(1.166 - (0.0073 \times \text{STK})) \times \text{YG}$ *</td>
</tr>
<tr>
<td>Corn silage</td>
<td>ton</td>
<td>$(9.50 - (0.06 \times \text{STK})) \times \text{YG}$ *</td>
</tr>
<tr>
<td>Soybeans</td>
<td>bu</td>
<td>$(2.2 - (0.0183 \times \text{STK})) \times \text{YG}$</td>
</tr>
<tr>
<td>Wheat</td>
<td>bu</td>
<td>$(2.71 - (0.017 \times \text{STK})) \times \text{YG}$</td>
</tr>
<tr>
<td>Alfalfa</td>
<td>ton</td>
<td>$(55.71 - (0.38 \times \text{STK})) \times \text{YG}$</td>
</tr>
</tbody>
</table>

* - Fertilizer Recommendations Guide  SDSU EC750
Making Recommendations

• What does it take to maintain the soil fertility?
• Supply the crop nutrient removal rates
  – How many pounds of the nutrient is removed?

<table>
<thead>
<tr>
<th>Crop</th>
<th>Unit</th>
<th>P$_2$O$_5$</th>
<th>K$_2$O</th>
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<tbody>
<tr>
<td>Corn</td>
<td>bu</td>
<td>0.32 – 0.43</td>
<td>0.22 – 0.29</td>
</tr>
<tr>
<td>Corn silage</td>
<td>ton</td>
<td>2.7 – 3.5</td>
<td>7 - 9</td>
</tr>
<tr>
<td>Soybeans</td>
<td>bu</td>
<td>0.72 – 0.83</td>
<td>1.2 – 1.4</td>
</tr>
<tr>
<td>Wheat</td>
<td>bu</td>
<td>0.5 – 0.6</td>
<td>0.27 – 0.35</td>
</tr>
<tr>
<td>Alfalfa</td>
<td>ton</td>
<td>6 – 13</td>
<td>43 – 60</td>
</tr>
</tbody>
</table>

– Compiled from NCR state extension publications
K Removal and Soil K Trends from ISU Research plots

Villavicencio and Mallarino, 2011

Cumulative K Removal with Grain Harvest (kg K ha\(^{-1}\))

Cumulative K Removal with Harvest (kg K ha\(^{-1}\))

Soil-Test K (mg kg\(^{-1}\))

Year

Villavicencio and Mallarino, 2011
Soil Potassium

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Potassium sample distribution: South Dakota

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- 2015: 133,310

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</tr>
<tr>
<td>41-80</td>
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</tr>
<tr>
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<td>50</td>
</tr>
<tr>
<td>281-320</td>
<td>60</td>
</tr>
<tr>
<td>&gt;320</td>
<td>70</td>
</tr>
</tbody>
</table>
What else impacts K variability?

- Crop nutrient uptake rates and K leaching from stover.
  - Differs with crop
  - Is rainfall dependent

Oltmans and Mallarino, ISU 2011
What else impacts K variability?

- Wetting and drying cycles.
- Temperature extremes.
History of Moist soil analyses

• Observation that drying affects measured K has been around since the 1920’s
  – J.L. Steenkamp, (1928)
  – O.J. Attoe, (1947)
  – Haby, et al. (1988)

• Common observations
  – Difference (wet vs. dried) is soil dependent
  – Higher rate of drying yields general positive bias
  – Difference relates to native K abundance
Moist K vs Dry Soil Test K

P. Barbagelata, 2006 (ISU PhD dissertation)
Observed Wet K Trend

- Differences diminished over the season, Fall 2013
Observed Wet K Trend

Comparing K Extraction Methods

- Moist K
- Dry K
- Linear (Moist K)
- Linear (Dry K)

Weekly Average Soil K, ppm

Weeks of the year, 2014
Observed Wet K Trend

Comparing K Extraction Methods
High and Low separated at 200 ppm

Weekly Average Soil K, ppm

Weeks of the year, 2014
Observed Wet K Trend
Potassium Levels by Method

Mean monthly value in each range

- Moist K, Low
- Dry K, Low
- Moist K, Hi
- Dry K, Hi

K, ppm

4/30/2014
5/29/2014
6/30/2014
8/6/2014
09/16/14
10/31/14
11/24/14
12/22/14
ISU research on Moist K

Mallarino et al., 2012 (data 2001 - 2006)
Observed Wet K Trend

Dry to Wet K Ratio (Dry K/Wet K) vs Wet K

Fall 2014

Dry K/Wet K vs Wet K

Wet K, ppm

Observed Wet K Trend
Observed Wet K Trend

Spring 2014

Dry K/Wet K vs Wet K, ppm

- March-April
- May
- June
- July-Aug

Log. (March-April)
Log. (May)
Log. (June)
Log. (July-Aug)
Log. (July-Aug)
Observed Wet K Trend

Comparing K Extraction Methods
High and Low separated at 200 ppm

Weekly Average Soil K, ppm

Weeks of the year, 2014
Potassium recommendations

• Base Saturation recommends that the level be 2 – 7% of CEC.

• Sufficiency level recommends a level of 150 – 200 ppm.

• Which is right?

![Graph showing relative yield percentage vs. soil test K in ppm]
## Potassium recommendations

To change a soil with 75 ppm K

<table>
<thead>
<tr>
<th>CEC</th>
<th>as % K sat</th>
<th>as ppm K in soil</th>
<th>ppm K to get to 5% of CEC</th>
<th>K$_2$O build amount</th>
<th>Over 5 years lbs K$_2$O/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>5.1</td>
<td>(.05*10)*390 = 195</td>
<td>195-75 = 120</td>
<td>960</td>
<td>192</td>
</tr>
<tr>
<td>15</td>
<td>3.4</td>
<td>(.05*15)*390 = 292</td>
<td>292-75 = 217</td>
<td>1736</td>
<td>347</td>
</tr>
<tr>
<td>20</td>
<td>2.6</td>
<td>(.05*20)*390 = 390</td>
<td>390-75 = 315</td>
<td>2520</td>
<td>504</td>
</tr>
<tr>
<td>25</td>
<td>2.1</td>
<td>(.05*25)*390 = 487</td>
<td>487-75 = 412</td>
<td>3296</td>
<td>659</td>
</tr>
<tr>
<td>30</td>
<td>1.7</td>
<td>(.05*30)*390 = 585</td>
<td>585-75 = 510</td>
<td>4080</td>
<td>816</td>
</tr>
</tbody>
</table>

* Includes the factor of 8 lbs of K$_2$O needed to raise the test level by 1 ppm
Outreach & Education

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Ellsworth, IA 50075
Thank you