Potassium for corn: Soil test K and yield inconsistencies

John S. Breker
Soil Scientist, AGVISE Laboratories

2018 AGVISE Soil Fertility Seminars
January 9-11, 2018
Potassium deficiency in corn

Deficiency symptoms
• Chlorosis, necrosis of outer leaf margin

Mobile nutrient in plant
• Expressed in lower leaves
Potassium deficiency in corn

Near Lisbon, ND (Aug. 2016)
Soil K: 47 ppm

Plot 106
0 K$_2$O/ac
174 bu/ac

Plot 107
150 K$_2$O/ac
226 bu/ac
Acreage changes in North Dakota

Harvested area (thousand acres)

Year

Corn  Soybean  Wheat

Typical grain K removal for principal crops at various yields

Change to corn/soybean production removing K at twice the rate

Revisiting potassium in North Dakota

- Increase in corn/soybean acreage
  - Higher yields, higher K export
- More soil tests below soil K critical level
  - 1980: 3% of samples (Nelson, 1980)
  - 2010: 17% of samples (Fixen et al., 2010)
  - 2015: 16% of samples (IPNI, 2016)
- Potash price spike
  ~$150/ton (1980-early 2000s)
  $853/ton (2008)
- General lack of soil K research (high native K fertility)


Soil samples with less than 150 ppm K

AGVISE Laboratories
Fall 2017 samples (0-6”)

MB

ND

SD

MN
Soil testing for potassium

Standard method in North Central region:
1.0 M NH₄OAC (pH 7) extraction on dry soil

Clay mineral surface

Exchangeable K⁺

Displaced K⁺

NH₄⁺ ion

AGVISE LABORATORIES
Scrutiny of soil testing method

Standard method:

1.0 M NH$_4$OAC (pH 7) extraction on dry soil

- Effect of sample drying on extractable K
- Inconsistent yield responses to K fertilization
- Plant availability of nonexchangeable K
- Seasonal soil test K variation
Objectives

1. Evaluate corn yield response to K fertilization
   - Broadcast potash (KCl, 0-0-60)
   - Six rates: 0 to 150 lb K$_2$O acre$^{-1}$

2. Identify adequate soil K test method
   - Determine STK critical level (STK$_{CL}$)

3. Assess seasonal soil K variation
Potassium deficiencies exist in NoDak!
Yield response prediction by soil test class

<table>
<thead>
<tr>
<th>Soil K test class (mg kg(^{-1}))</th>
<th>VL 0-40</th>
<th>L 41-80</th>
<th>M 81-120</th>
<th>H 121-160</th>
<th>VH 161+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of sites in soil test class</td>
<td>0</td>
<td>3</td>
<td>6</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Number of sites with significant yield response</td>
<td>---</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Probability of yield response</td>
<td>---</td>
<td>67%</td>
<td>33%</td>
<td>40%</td>
<td>20%</td>
</tr>
</tbody>
</table>

- Six of 14 sites below 160 mg kg\(^{-1}\) DK had significant yield increases
- Drier years of 2015 and 2016 had more inconsistencies
- Two of six responsive sites had significant yield decreases at 150 lb K\(_2\)O acre\(^{-1}\)

Soil test methods evaluated

Exchangeable K

- Ammonium acetate
  - Air-dried soil
  - Field-moist soil
- Interpretation using sufficiency and BCSR approaches

Exchangeable K AND nonexchangeable K

- Ion-exchange resin capsule (UNIBEST Inc.)
  - 168-hour incubation
- Sodium tetr phenylboron (Cox et al., 1999)
  - 5-min, most reactive nonexchangeable K
  - 168-hour, total nonexchangeable K

Soil test K and corn grain yield response

Standard method (NH₄OAc on air-dry soil) had best correlation with yield response

**Linear-plateau model of relative corn yield and plant-available K methods**

<table>
<thead>
<tr>
<th>Method†</th>
<th>STK at plateau</th>
<th>r²</th>
<th>P&gt;F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air-dry K</td>
<td>93</td>
<td>0.49</td>
<td>0.02</td>
</tr>
<tr>
<td>Field-moist K</td>
<td>61</td>
<td>0.47</td>
<td>0.02</td>
</tr>
<tr>
<td>TBK 5 min</td>
<td>333</td>
<td>0.33</td>
<td>0.09</td>
</tr>
<tr>
<td>TBK 168 h</td>
<td>2028</td>
<td>0.30</td>
<td>0.12</td>
</tr>
<tr>
<td>Resin K</td>
<td>NA</td>
<td>0.16</td>
<td>0.14</td>
</tr>
<tr>
<td>K sat. (%)</td>
<td>1.56</td>
<td>0.42</td>
<td>0.04</td>
</tr>
</tbody>
</table>

† DK and MK are 1 M NH₄OAC extractable K on air-dry and field-moist soil, respectively; TBK is tetraphenylboron extractable K; RK is resin extractable K; K sat is K saturation.

Soil test K and plant tissue K

Soil test K had strong correlations with plant tissue K at growth stages V5 and VT

Unfortunately, plant tissue K did not relate well with grain yield response…

Bury our heads or look deeper?
Soil mineralogy and potassium: SOIL 101 refresher

This sleep aid has not been approved by the U.S. Food and Drug Administration (FDA).
Quick review: Soil components

- Water: 25%
- Air: 25%
- Organic matter: 5%
- Mineral: 45%

Particle-size classes:
- Sand
- Silt
- Clay

Mineralogically distinct
Primary K minerals

**K-feldspar**
Si-O framework

**Mica**
Al-Si-O sheets


Smectite and Vermiculite (swelling/expanding)

2:1 clay layers
- Two tetrahedral Si-O layer
- One octahedral Al-O layer

Expansible interlayer
- Hydrated interlayer cations
- Hydrated = water around cation, bigger cation size

Expansible interlayer space

Illite
(non-expanding)

2:1 clay layers

Higher layer charge than vermiculite or smectite

Interlayer collapsed
- **Dehydrated interlayer cations**

**Collapsed interlayer**
**Fixed K**

Clay layer charge

- Positive cations (Ca$^{2+}$, Mg$^{2+}$, Na$^+$, K$^+$) balance negative clay layer charge
- Low layer charge $\rightarrow$ more expansion

<table>
<thead>
<tr>
<th></th>
<th>Smectite</th>
<th>Vermiculite</th>
<th>Illite/mica</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layer charge</td>
<td>-0.2 to -0.6</td>
<td>-0.6 to -0.9</td>
<td>-0.75 to -1.0</td>
</tr>
<tr>
<td>(charge/half unit cell)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expansibility</td>
<td>High</td>
<td>Moderate</td>
<td>None</td>
</tr>
</tbody>
</table>

Gray area between smectite and vermiculite. Transitional minerals, some refer to high-charge smectites (beidellite).

K fixation = interlayer K + (F_{contraction} > F_{expansion})

- Interlayer expansion + K release → Increase in exchange capacity
- Interlayer collapse + K fixation → Decrease in exchange capacity

Mica weathers to other clays: existing as mixed-layer intergrades

Dehydrated $K^+$ ion
Hydrated $K^+$ ion
Hydrated $Ca^{2+}$ ion

Broken edge

Edge positions

Interlayer positions

Vermiculite layer

Vermiculite layer

Vermiculite layer

Mica layer

Mica layer

Solution $K^+$

Planar positions

Wedge positions


Potassium availability

How does $K^+$ get to the root?
Soil K cycle: from mineral to root

Plant roots only take up $K^+$ from soil solution.

Whatever the K source:
- fertilizer
- manure/residue
- mineral
$K^+$ must enter soil solution.

Soil K reactions are dynamic.

Additions
Transformations
Losses
Factors affecting soil K availability

Static
• Soil texture
  • CEC
  • Soil water content
• Soil organic matter
• Mineralogy
  • K-feldspar
  • Smectite, illite, etc.

Dynamic
• Soil water content
  • K diffusion
  • K fixation/release
• Addition/removal
  • Fertilizer K
  • Crop K uptake
  • Crop residue K return
K\(^+\) diffuses to plant roots through water films

Low water content makes K\(^+\) diffusion harder:
- less water
- longer diffusion path
- more soil adsorption-desorption interaction

\[0.0\quad 0.2\quad 0.4\quad 0.6\quad 0.8\quad 1.0\]
\[0\quad 0.5\quad 1\]

Tortuosity

\[\text{Water-filled porosity (}\Theta/\Theta_s\text{)}\]

Wetting/drying cycles promote K fixation

- Wet/dry cycles can convert smectite to illite
- Redistribution of interlayer cations, allowing layer collapse
- Greater for high layer-charge smectite (beidellite)
- Beidellite identified in Red River Valley


New from NDSU October 2017

Resulting from

• Recalibration of potassium soil test for corn in North Dakota (2014-2016)

• Soil mineralogical survey of North Dakota (2014-2017)

K-feldspar content of total soil minerals in North Dakota

D.W. Franzen, North Dakota State Univ. (personal communication, 2017)
Smectite/illite groups require different soil test K critical levels

High smectite/illite
• $\text{STK}_{\text{CL}} = 200 \text{ ppm}$, when dry

Low smectite/illite
• $\text{STK}_{\text{CL}} = 150 \text{ ppm}$

D.W. Franzen, North Dakota State Univ. (personal communication, 2017)
Two clay types, two STK critical levels

Low smectite/illite (ratio < 3.5)
- More illite, more interlayer K
- Lower potential for layer collapse when dry
- STK_{CL} = 150 ppm

High smectite/illite (ratio > 3.5)
- Less illite, less interlayer K
- Greater potential for layer collapse when dry
- STK_{CL} = 200 ppm

Smectite/illite ratio of clay fraction of soils in North Dakota

Soils with smectite/illite ratio > 3.5 (gray area), \( \text{STK}_{\text{CL}} = 200 \text{ ppm} \)

D.W. Franzen, North Dakota State Univ. (personal communication, 2017)
Potassium rate limits (broadcast)

Low rate: 60 lb K$_2$O acre$^{-1}$
- Minimum amount of fertilizer K material (100 lb potash acre$^{-1}$) needed for adequate distribution to enough plants
- Banded K lower rates?

High rate: 120 lb K$_2$O acre$^{-1}$
- Corn yield reduction often occurring at 150 lb K$_2$O acre$^{-1}$
- Cause still under investigation

D.W. Franzen, North Dakota State Univ. (personal communication, 2017)
Why not minimum broadcast rate for phosphorus then?

• Plant requirement for K much greater than P

<table>
<thead>
<tr>
<th>Corn yield (bushel acre⁻¹)</th>
<th>Plant P₂O₅ uptake (lb acre⁻¹)</th>
<th>Plant K₂O uptake (lb acre⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>102</td>
<td>270</td>
</tr>
</tbody>
</table>

• Root interception per granule (lower P analysis)

<table>
<thead>
<tr>
<th>Fertilizer</th>
<th>Nutrient mass per granule (mg)</th>
<th>Granules per acre (assume 20 lb acre⁻¹ rate)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potash, 60% K₂O</td>
<td>14.4</td>
<td>628,000</td>
</tr>
<tr>
<td>MAP, 52% P₂O₅</td>
<td>11.6</td>
<td>782,000</td>
</tr>
</tbody>
</table>

Fertilizer calculations based on PCS product information
www.potashcorp.com/media/POT_SS_FER_MAP.pdf
Conclusions

No loose ends here. Okay, maybe a few.
How will AGVISE handle this?

• Ongoing discussion this winter
• We serve multi-state and -province region
  • Soil mineralogical data is sparse in most areas

• For now, North Dakota clients encouraged to consult NDSU clay survey to determine $STK_{CL}$ for their local area
Which $\text{STK}_{\text{CL}}$ do you consider?

$\text{STK}_{\text{CL}} = 200$ ppm
- High smectite/illite (ratio$>$3.5)
  - Higher risk of dry conditions
  - $\text{STK}_{\text{CL}}$ variability in composite samples

$\text{STK}_{\text{CL}} = 150$ ppm
- Low smectite/illite (ratio$<$3.5)
  - $\text{STK}_{\text{CL}}$ of 150 ppm still valid for many soils
  - Avoid unnecessary K

Between 150 – 200 ppm?
Risk management (how close can you be?)
- or -
Strip trials, you can do this!
Soil samples in the 150-200 ppm K critical level “gray area”
Going forward

• Crop response to potassium is difficult to predict
  • Soil test K only gets us so far

• Mineralogy addresses some inconsistencies
  • High smectite/illite soils require higher initial STK, when dry
  • Yet, not clear for lower STK soils with high K-feldspar or illite content that provide ample plant available K

• Soil water content for growing season is not predictable
  • Crop response will be greater in dry years
  • Computer models? Limited usefulness if model predicts deficiency too late for K application and correction
Thank you for your attention

Acknowledgements
North Dakota Corn Council

Dr. David W. Franzen
NDSU Extension Soil Specialist

Manbir Rakkar

Honggang Bu (mobile app developer)
Dr. Lakesh Sharma
Eric Schultz
Austin Kraklau
Conner Swanson
Makenzie Ries
Kevin Horsager
Dr. Shiny Mathews
Dr. Thomas DeSutter
Dr. Amitava Chatterjee
Questions?

johnb@agvise.com
@jsbreker