Potassium for Corn in North Dakota: Challenges in Response Prediction

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Our Potassium Journey

• Potassium nutrition for corn
• Revising the recommendations
• Potassium rate study: 2015-2016
  – Soil test comparison
  – Yield response to fertilization
  – Sampling time for soil potassium
• Potassium mineralogy
Potassium nutrition for corn

Deficiency symptoms

• Chlorosis, necrosis of outer leaf margin

• Mobile nutrient in plant
  – Expressed in lower leaves
Potassium nutrition for corn

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

John S. Breker, NDSU

Plot 106
0 K₂O/ac
174 bu/ac

Plot 107
150 K₂O/ac
226 bu/ac

John S. Breker, NDSU
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Increase in ND corn/soybean acres

**Acreage changes**

<table>
<thead>
<tr>
<th>Year</th>
<th>Corn (thousand acres)</th>
<th>Soybean (thousand acres)</th>
<th>Wheat (thousand acres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1879</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1987</td>
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<td>1938</td>
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<td></td>
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<tr>
<td>1968</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1999</td>
<td></td>
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</tbody>
</table>

**Yield increase**

<table>
<thead>
<tr>
<th>Year</th>
<th>Corn (bushel/acre)</th>
<th>Soybean (bushel/acre)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1879</td>
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</tr>
</tbody>
</table>

Data source: USDA-NASS
Typical K removal in grain for principal ND crops at various yields

Change to corn/soybean production removing K at twice the rate
Soil samples with less than 150 ppm K

Fall 2016 samples
(0-6” samples)

Data provided courtesy of AGVISE Laboratories, Northwood, ND.

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Revisiting potassium in North Dakota

• Increase in corn/soybean acreage
  – Higher yields, higher K export
• More soil tests below critical level
  – 1980: 3% of samples (Nelson, 1980)
  – 2010: 17% of samples (Fixen et al., 2010)
• Potash price spike
  ~$150/ton (1980-early 2000s)
  $853/ton (2009)
Developing a recommendation: Find the soil test critical level

Yield related to amount of plant-available nutrient in soil

Image from https://courses.cit.cornell.edu/css412/mod3/ext_m3_pg3.htm
Soil testing for potassium

Standard method in North Central region: 1.0 M NH$_4$OAC (pH 7) extraction on dry soil
Scrutiny of soil K test method

Standard method in North Central region:

1.0 M NH₄OAC (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
Study objectives

1. Evaluate corn yield response to K fertilization
2. Identify adequate soil K test method
   • Determine critical level
3. Assess seasonal soil K variation
Potassium rate trials

2015: 13 sites
2016: 6 sites
Study Timeline

Spring

- RCBD with four reps
  - Expt. Unit: 10 ft x 30 ft
- Urea, MAP, gypsum broadcast
- Six KCl (0-0-60) rates
  - 0, 30, 60, 90, 120, 150 lb K₂O/acre
  - Shallow incorporation (2-3 inches)
Study Timeline

Summer
• Soil samples
  – Biweekly: 0-6 inch
• Plant samples (2016)
  – V5: Whole plant
  – VT: Ear leaf

Fall
• Harvest one 30-foot corn row
• Yield, grain moisture, test weight
Soil test methods evaluated

• 1.0 M NH₄OAC (pH 7) extraction, 5 minute
  – Air-dried soil, ground
  – Field-moist soil, sieved

• Ion-exchange resin capsule, 168 hour incubation (UNIBEST, Inc.)

• Sodium tetraphenylboron extraction (Cox et al., 1999)
  – 5 minute, most reactive nonexchangeable K
  – 168 hour, total nonexchangeable K

• Soil mineralogy (ACT Labs, Ontario)
What K pools does a soil test target?

From McLean and Watson, 1985

**Exchangeable K**
K ions adsorbed onto clay surfaces

**Nonexchangeable K**
K ions trapped in wedge sites or interlayer spaces

**NH₄OAc**
- Dry soil: layers warp/collapse
- Moist soil: field condition

**Tetraphenylboron**
- Releases interlayer-K

**Resin**
- Equilibrates with exchangeable/interlayer-K

From McLean and Watson, 1985
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## Correlations among K extraction methods

<table>
<thead>
<tr>
<th></th>
<th>Dry K</th>
<th>Moist K</th>
<th>TBK 5min</th>
<th>TBK 168hr</th>
<th>Resin K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry K</td>
<td>1.00</td>
<td>0.96</td>
<td>0.94</td>
<td>0.75</td>
<td>0.67</td>
</tr>
<tr>
<td>Moist K</td>
<td>1.00</td>
<td></td>
<td>0.89</td>
<td>0.70</td>
<td>0.70</td>
</tr>
<tr>
<td>TBK 5min</td>
<td></td>
<td></td>
<td>1.00</td>
<td>0.88</td>
<td>0.46</td>
</tr>
<tr>
<td>TBK 168hr</td>
<td></td>
<td></td>
<td></td>
<td>1.00</td>
<td>0.14</td>
</tr>
<tr>
<td>Resin K</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.00</td>
</tr>
</tbody>
</table>

- **Dry K**
- **Moist K**
- **TBK 5min**
- **TBK 168hr**
- **Resin K**

**Correlations**

- Good correlation between NH$_4$OAC and 5-min TBK
- TBK and resin methods not related, different mechanisms
Sample drying increased NH$_4$OAc-extractable K

- Average: 1.26 times higher
- Range: 0.8-2.4
- Increase higher for low K soils
Smectitic soils released more K

\[ y = 1.01 + 0.0562x \]
\[ r^2 = 0.45, P < 0.01 \]
And then drying got complicated...

Figure 1.—K extracted with neutral 1N NH₄Ac from soils that had been dried to various moisture levels after increments of KCl had been added.

From Scott et al., 1957
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## 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 significant 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 150 ppm critical level responded (less than half)
Soil test K and yield response: NH₄OAc K on dry and moist soil

- Dry method still superior to moist method
Soil test K and yield response: Tetraphenylboron K, 5-min and 168-hr

- Not better than NH₄OAc methods
Soil test K and yield response: Resin K & %K saturation

- Resin method not significant, linear relationship
- K saturation not better than sufficiency level

\[ Y = 0.95(1-0.619e^{-2.16x}) \]
\[ r^2 = 0.39, P = 0.05 \]
High $K_2O$ rate yield decrease, a response with a tail?
High K₂O rate yield decrease, a response with a tail?

<table>
<thead>
<tr>
<th>Site</th>
<th>Grain yield</th>
<th>Significant</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fertilizer K rate (lb K₂O acre⁻¹)</td>
<td>Linear</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>30</td>
</tr>
<tr>
<td>F115</td>
<td>192 ab†</td>
<td>200 a</td>
</tr>
<tr>
<td>F215‡</td>
<td>181 c</td>
<td>190 bc</td>
</tr>
<tr>
<td>GD16</td>
<td>165 b</td>
<td>173 b</td>
</tr>
<tr>
<td>LB16</td>
<td>160 b</td>
<td>190 a</td>
</tr>
</tbody>
</table>

†Within rows, treatment means followed by the same letter are not significantly different.
‡LSD alpha-value changed to 0.1 significance level.
Correlation between Soil Test K and Tissue K

Leaf stage V5 (whole plant)

\[ Y = 3.4(1-3.56\times 0.0327x) \]
\[ r^2 = 0.59, P < 0.01 \]

\[ Y = 3.5(1-1.63\times 0.0243x) \]
\[ r^2 = 0.59, P < 0.01 \]
Correlation between Soil Test K and Tissue K

Leaf stage VT (ear leaf)

\[
Y = 0.0074x + 0.47 \\
Y = 0.0065x + 0.57
\]

\[r^2 = 0.83, P < 0.01\]
Does tissue K help predict yield?

![Graph showing the relationship between tissue K and grain yield with regression lines and R² values.]

- V5 R² = 0.02
- VT R² = 0.21
Does tissue K help predict relative yield response?

![Graph showing relative yield response vs. tissue K (%)]

- V5: $R^2 = 0.03$
- VT: $R^2 = 0.00$
What good is tissue K analysis?

In-field comparison for deficiency diagnosis

From http://xkcd.com/1725/
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Sampling time: Sinusoidal pattern

Soil K trend
- Highest in spring
- Lowest late summer

2015: 12 of 13 sites followed sinusoidal pattern over time
Sampling time: Sinusoidal pattern

2016: Rainfall variability, not able to combine (Dry K, 5/6 sites)
Sampling time and soil K levels

• Soil K trends
  – Highest in late May or early June
  – Lowest in late summer
  – Crop K uptake, soil water use

• Sinusoidal pattern within year
Potassium Mineralogy: An Unexpected Journey

Primary minerals
- K-feldspar
- Micas

Clays
- Illite, vermiculite
- Smectite
  - Montmorillonite
  - Beidellite
Nonexchangeable K release may be faster than we thought

From Sparks and Huang, 1985

1000 hours ≈ 42 days

← 78 ppm

From Sparks and Huang, 1985
K-feldspar weathering

- Deep weathering pits
- Increased surface area with weathering

From Huang, 1989
Mica weathering

• Biotite
  – Mostly weathered out of soils

• Muscovite
  – Rate of K release 95% slower than biotite (Feigenbaum et al., 1981)

From Fanning et al., 1989
Mica weathering

- Weathers to
  - Hydrous mica
  - Illite
  - Vermiculite
  - Smectite

From Fanning et al., 1989
K-fixation sites on weathered mica/illite

- Mica $\rightarrow$ Expansible 2:1 layer clay
- “Tight”, high K-affinity fixation sites
  - Frayed edges
  - Interlayer wedges

From Sparks and Huang, 1985
Interlayer-K exchangeability

- $K^+$ fits into wedges, may collapse layer and revert to mica/illite, “fixed K”

From Sparks and Huang, 1985
Conversion of smectite to illite after 100 wet/dry cycles

Smectite types
Montmorillonite
- Low-layer charge
- Dominant clay type

Beidellite
- High-layer charge
- Identified in Minnesota side of glacial Lake Agassiz (Badroui et al., 1987)

From Sucha and Siranova, 1991
Looking back at sample drying

Figure 1.—K extracted with neutral 1N NH₄Ac from soils that had been dried to various moisture levels after increments of KCl had been added.

From Scott et al., 1957
Site analysis: K-bearing mineral content
Site analysis:
Clay mineralogy
Does mineralogy help explain yield response?

Factor analysis:
Common factors between variables
• Mineralogy
• Relative Yield
Summary

• Sample drying increased NH$_4$OAc K
  – Variable between soils, mineralogy
• Dry K test failed to predict half of responses
  – Dry K test best predictor of yield response
• Yield occasionally tails off at high K rates
• Soil K levels follow a sinusoidal pattern over time
• Mineralogy important, but relationship not clear
Conclusions

• Dry K soil test not sufficient for directing K fertilizer recommendations
  – Moist K, TBK may not be any better
• Take soil samples at same time every year
• Potassium is far from simple
Thank you!

Acknowledgements:
Kevin Horsager
Dr. Shiny Mathews
Dr. Lakesh Sharma
Eric Schultz
Austin Kraklau
Conner Swanson
Makenzie Ries

“Tartan” twinning of K-feldspar
“There is a lot that we know [about potassium]. I don’t know if it is all useful for making a recommendation.”

-Dr. Sylvie Brouder (Purdue Univ.), 2014 SSSA Meeting
References


