The Potassium Crusade: On the Cusp of the Age of Enlightenment

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Symposium: Soil Potassium Tests and Their Relationship to Plant Availability and Native Mineralogy
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Nov. 3, 2014
Wikipedia on “crusading”

Definition:
• A grand concerted effort toward some purportedly worthy cause.

On religious crusades of the 11th – 13th centuries:
• Crusading attracted men and women of all classes.
• ...judgment of the conduct of crusaders has varied widely from laudatory to highly critical...
IMC Tour
2001

1 min per year or 20 seconds per site-year
The Tri-State Equations

**Buildup Equation**

For P: \( \text{lb} \ P_2O_5 / A \) to apply = \([(\text{CL} - \text{STL}) \times 5] + (\text{YP} \times \text{CR}) \)

For K: \( \text{lb} \ K_2O / A \) to apply = \([(\text{CL} - \text{STL}) \times ((1 + (0.05 \times \text{CEC}))) + (\text{YP} \times \text{CR}) + 20 \)

**Maintenance Equation**

For P: \( \text{lb} \ P_2O_5 / A \) to apply = \( \text{YP} \times \text{CR} \)

For K: \( \text{lb} \ K_2O / A \) to apply = \( (\text{YP} \times \text{CR}) + 20 \) (for non-forage crops)

**Drawdown Equation**

For P: \( \text{lb} \ P_2O_5 / A \) to apply = \( (\text{YP} \times \text{CR}) - [(\text{YP} \times \text{CR}) \times (\text{STL} - (\text{CL} + 15))/10] \)

For K: \( \text{lb} \ K_2O / A \) to apply = \( (\text{YP} \times \text{CR}) + 20 - [(((\text{YP} \times \text{CR}) + 20) \times (\text{STL} - (\text{CL} + 30))/20] \) (for non-forage crops)
Research Purpose / Questions

Main objectives:
• Address known limitations with the “Tri-State Recommendations” for certain Indiana soils
• Assess: Soil K levels for optimum soybean production > those for optimum maize production
• Assess: Soil critical levels (CL) developed for heavily tilled soils = CLs for systems with reduced tillage / K stratification

Additional objectives:
• Assess: Annual applications > biennial applications
• Assess: Historic K removal values for maize & soy
• Assess: TPB vs NH$_4$OAc Extractable K as routine STK

Today’s focus: Effort to derive soil- &/or crop specific Critical Levels using NH$_4$OAc ext. on air dry samples
Indiana “5-yr” K study ~ 5 Purdue Ag. Centers (PAC); Established 1997

- DPAC: Chisel; Blount-Pewamo (Glynwood)
- PPAC: Chisel; Tracy
- NePAC: No-Till; Glynwood-Haskins
- SePAC: No-Till; Cobbsfork
- TPAC: No-Till; Toronto-Millbrook

Tri-State CL = 75 + (2.5 x CEC) for all crops

<table>
<thead>
<tr>
<th>Location</th>
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<th>STK at T₀</th>
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CEC (cmol kg⁻¹); CL and STK (mg kg⁻¹)
Values are means of 0-10 and 10-20 cm depths
Experimental Design

• Maize-Soy rotation: 2 adjacent fields per location for both crops every year
• Randomized (K rates), split-plot design (A Vs B) w/ 3 or 4 replicates
• Broadcast K application in early spring
• Annual K rates: 0, 25, 50, 100, 150 kg K ha⁻¹
• Biennial K rates: 0, 50, 100, 150, 300 kg K ha⁻¹

Sampling Protocols

Plant Material

• Whole plant: V4-V6 (M); R1 (S)
• Tissue (occasional): Earleaf (M), trifoliate (S)
• Grain: mass & K removal

Soil

• Annually in-season: V4-V6 (M), R1 (S); 0-10 & 10-20 cm depths
• Biennially post harvest: fall of 2nd yr in 2 yr rotation prior to biennial application; full profile
• NH₄OAc Ext. K plus others
Indiana “5-yr” K study ~ 5 Purdue Ag. Centers (PAC); Established 1997

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</tr>
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<td>98</td>
<td>49</td>
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CEC (cmol kg⁻¹); CL and STK (mg kg⁻¹)

Values are means of 0-10 and 10-20 cm depths
First 6 yrs (3 M-S cycles): Big problem…

| Location | CEC (cmol kg\(^{-1}\)) | CL (mg kg\(^{-1}\)) | STK at \(T_0\) | STK at \(T_{6yr}\) \\
<table>
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<td>7.0</td>
<td>93</td>
<td>119</td>
<td>86, 243 (Y)</td>
</tr>
<tr>
<td>NePAC</td>
<td>11.1</td>
<td>103</td>
<td>86</td>
<td>72, 178 (Y)</td>
</tr>
<tr>
<td>SePAC</td>
<td>9.1</td>
<td>98</td>
<td>49</td>
<td>28, 103 (Y)</td>
</tr>
<tr>
<td>TPAC</td>
<td>15.3</td>
<td>113</td>
<td>159</td>
<td>119, 277 (Y)</td>
</tr>
</tbody>
</table>

**Tri-State CL = 75 + (2.5 x CEC) for all crops**

CEC (cmol kg\(^{-1}\)); CL and STK (mg kg\(^{-1}\))
Values are means of 0-10 and 10-20 cm depths (annual K app. Treatments)
Maize & Soy yields in 2002 as a function of STK (0 – 20 cm depth)

Not much happening even in a dry year…
What’s a knight-errant “questing” for the Holy Grail (the perfect soil K test, a better recommendation, etc.) to do…?
1) Keep going (8yr window): stop adding K; stop intensively sampling
2) Restart sampling protocols (2009 - ?)
15 years later (2011): Now we can identify those CLs...??

Tri-State CL = 75 + (2.5 x CEC) for all crops

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<th>STK at T₀</th>
<th>STK at T₆yr K = 0, 150 (sig.)</th>
<th>In-season STK at T₁₅yr Range (Fall T₁₅yr)</th>
<th>Mean (All-Yr) Maize Yield K=0, 150 (sig)</th>
<th>Mean (All-Yr) Soy Yield K=0, 150</th>
</tr>
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<td>15.4</td>
<td>114</td>
<td>85</td>
<td>73, 161 (Y)</td>
<td>57 – 280 (59 – 236)</td>
<td>9177, 9788 (N)</td>
<td>3211, 3332 (N)</td>
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<tr>
<td>PPAC</td>
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<td>93</td>
<td>119</td>
<td>86, 243 (Y)</td>
<td>41 – 153 (32 – 94)</td>
<td>11164, 12164 (Y)</td>
<td>3426, 3781 (Y)</td>
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<tr>
<td>NePAC</td>
<td>11.1</td>
<td>103</td>
<td>86</td>
<td>72, 178 (Y)</td>
<td>39 – 164 (46 – 119)</td>
<td>7844, 9238 (Y)</td>
<td>2703, 2992 (Y)</td>
</tr>
<tr>
<td>SePAC</td>
<td>9.1</td>
<td>98</td>
<td>49</td>
<td>28, 103 (Y)</td>
<td>20 – 56 (19 – 69)</td>
<td>5400, 7954 (Y)</td>
<td>2797, 3351 (Y)</td>
</tr>
<tr>
<td>TPAC</td>
<td>15.3</td>
<td>113</td>
<td>159</td>
<td>119, 277 (Y)</td>
<td>52 – 214 (57 – 209)</td>
<td>10333, 10882 (N)</td>
<td>3194, 3318 (N)</td>
</tr>
</tbody>
</table>

CEC (cmol kg⁻¹); CL and STK (mg kg⁻¹)
Values are means of 0-10 and 10-20 cm depths (annual K app. Treatments)
The art of the perfect calibration curve…

Standard Approach
1) Conduct multiple site-years of research
2) Visualize (“eyeball”)
3) Identify weird data, seek explanation & discard
4) Calculate relative yields
5) Aggregate site-years & fit function

https://extension.udel.edu/factsheet/interpreting-soil-phosphorus-and-potassium-tests/
Standard Approach requires some observations within every site-year that are known to be K sufficient (Note: Total K additions: K1=0, K2=150, K3=300, K4=600, K5=900 kg ha\(^{-1}\))

Maize yield trends in time ~ evidence residual K fertilizer still adequate?

Note: in 2011 K balance still positive for K5 (all sites), K4 (PPAC & TPAC)

R. Navarrete, 2013
Standard Approach requires STK levels be equilibrated with non-exchangeable K pools

Biennial trts. STK time series demonstrate equilibration effect

R. Navarrete, 2013
Alternatives to the standard approach to calibration: The data mining or “the data are what they are” approach

**Boundary Analysis** identifies CL as the level below which you know K is the limiting factor. Fit functions (Linear & Plateau or Spline) to mean of 3 to 5 highest yield observations per incremental increases in STK...
Universal CL below which you know you have a problem with K regardless of your soil series…

(compare to Tri-State CL range: \(93 - 114 \text{ mg kg}^{-1}\) for 0-20 cm depth increment)

Useful to know? Perhaps not given we are not making recommendations for those unaccustomed to fertilizer / fertilizing...

<table>
<thead>
<tr>
<th>Crop</th>
<th>Soil depth</th>
<th>Dataset Coeff*</th>
<th>C.I.**</th>
<th>Boundary Coeff</th>
<th>C.I.</th>
<th>Spline max†</th>
<th>R² Dataset</th>
<th>Boundary</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>0 - 10</td>
<td>99</td>
<td>94</td>
<td>104</td>
<td>66</td>
<td>62</td>
<td>70</td>
<td>111</td>
</tr>
<tr>
<td>Corn</td>
<td>10 - 20</td>
<td>39</td>
<td>37</td>
<td>41</td>
<td>38</td>
<td>35</td>
<td>40</td>
<td>75</td>
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<tr>
<td></td>
<td>0 - 20</td>
<td>48</td>
<td>46</td>
<td>51</td>
<td>49</td>
<td>46</td>
<td>51</td>
<td>87</td>
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<tr>
<td>Soybean</td>
<td>0 - 10</td>
<td>48</td>
<td>37</td>
<td>59</td>
<td>59</td>
<td>46</td>
<td>72</td>
<td>95</td>
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<tr>
<td></td>
<td>10 - 20</td>
<td>33</td>
<td>29</td>
<td>36</td>
<td>35</td>
<td>27</td>
<td>42</td>
<td>53</td>
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<tr>
<td></td>
<td>0 - 20</td>
<td>41</td>
<td>34</td>
<td>48</td>
<td>43</td>
<td>36</td>
<td>50</td>
<td>71</td>
</tr>
</tbody>
</table>

* Mean K\text{exch} where yield plateaus using the entire dataset and maximum yield subset (boundary)

** 95% confidence interval for the mean K\text{exch} coefficient of the entire dataset and maximum yield subset (boundary)

† Soil K\text{exch} at which maximum yield was observed by fitting a spline to the maximum yield subset (boundary)

R. Navarrete, 2013
## Boundary Analysis by Site (Linear Plateau fit only; 0-10 cm only!)

<table>
<thead>
<tr>
<th>Site</th>
<th>Corn Coeff*</th>
<th>Corn CI**</th>
<th>Soybean Coeff</th>
<th>Soybean CI</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>TPAC</td>
<td>77</td>
<td>72</td>
<td>81</td>
<td>117</td>
<td>104</td>
</tr>
<tr>
<td>SEPAC</td>
<td>44</td>
<td>41</td>
<td>47</td>
<td>57</td>
<td>40</td>
</tr>
<tr>
<td>DPAC</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>102</td>
<td>84</td>
</tr>
<tr>
<td>NEPAC</td>
<td>112</td>
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* Mean K<sub>exch</sub> concentration where yield plateaus

** 95% confidence interval for the K<sub>exch</sub> coefficient

† Standard error of the estimate

Note: Unlike analyses across sites, within site analysis shows higher CL for Soy Vs Maize

R. Navarrete, 2013
On-going work: Standard approach ~ developing a relationship of relative yield to STK... (Note: now have CL for DPAC Maize)
On-going work:
Standard approach ~ not first path taken because it involves more complex analyses.

**Standard Approach**

1) Conduct multiple site-years of research
   1) Use only plots w/ no recent K additions
2) Visualize (“eyeball”)
3) Identify weird data, seek explanation & discard
   1) Field logs, weather data, other limiting factors
4) Calculate relative yields
   1) Simulate expected “water limited yields” or other means of estimation when all observations may be K limited...
5)Aggregate site-years & fit function
   1) Move beyond LP, spline, etc.
On the Cusp of Enlightenment?

What do I/we know I/we know (or will know soon)?

• For any research field, we can identify a CL
• CLs are not a direct, linear function of CEC (our expectation an artifact of computationalizing / universalizing a local concept?)
• Soil K availability & plant K demand varies with $H_2O$
• STK varies with $H_2O$ (current & antecedent; status during extraction) & w/ the “mix” of the mixed mineralogy, etc.

What do we know we don’t know?

• The specific cause of unexpected STK results in a farmer’s field
• The exact probability of a response to K in any given farm field given a certain STK value.
• The exact $$$ value of the return on investment in a soil K test or an increment of fertilizer K.
On the Cusp of enlightenment? Business as usual or…

What are unpromising testable hypotheses for future research?
• The XXX extraction is a stand-alone, precise, accurate, universally useful approach to STK for soil- & crop-specific K recommendations
• To improve K recommendations, we just need more replicated calibration studies of crop response to STK

What are more promising testable hypotheses for future research?
• Farmer data (STK & yield) can contribute to soil- & crop-specific recommendations (Boundary Analysis approach)
• Quantifying plant-soil water relations will improve understanding of season-long plant K demand & inform STK interpretation
Relationship between ΔSTK in soil & net K addition differs from that of ΔSTK & net K removal but…

R. Navarrete, 2013

0-10 cm depth increment; annual K app.
Relationship of ΔSTK to system K balance may be about more than just positive Vs negative balances.
Where to next…?

- Keep the plots going
  - Really nail those CLs
  - Examine all kinds of ??s that require really K deficient plots
    - Nutrient interactions
    - Soil build from extreme deficiency
- Kill the plots & mine the data
- Make the data & plots available for other researchers/research questions
  - Who manages the exp.?
  - Where are the resources for long-term experiments?