Nutrient Balances in North American Soils

Fertilizer Outlook and Technology Conference
Tampa Marriott Waterside Hotel
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Terry L. Roberts
President, IPNI
Nutrient balance and 4R nutrient stewardship

CROPPING SYSTEM OBJECTIVES

Healthy environment

Source

Rate

Place

Time

Productivity

Profitability

Durability

Ecosystems

Services

Soil productivity

Adoption

Farm income

Working conditions

Quality

Yield stability

Return on investment

Net profit

Yield

Nutrient balance

Soil erosion

Nutrient loss

Water & air quality

Energy, Labor, Nutrient, Water

Resource use efficiencies:

Healthy environment

ENVIRO

MENTAL

NUTRIENT

AL

AND

4R NUTRIENT

STEWAR

SHIP

Biodiversity
Ten tenets of sustainable soil management

“Analogous to a bank account, it is also not possible to take more out of a soil than what is put in it without degrading its quality ... Thus, managed ecosystems are sustainable in the long term if the output of all components produced balance the input into the system.”

Source: Rattan Lal. J. Soil and Water Conservation 64(1): 20-21A
Nutrient Budgets ...

- useful insights into the balance between nutrient inputs and outputs in crop production
- unlike financial budgets ... only partial budgets because of inaccuracies in determining inputs/outputs
Nutrient additions to the field also include N fixation by legumes, atmospheric deposition and nutrients in irrigation water.

Losses also include soil erosion, leaching, denitrification, volatilization.

- **Fertilizer and manure additions**
- **1st yr uptake**
- **From soil**
- **Soil available nutrient reservoir**
- **Removed with harvest**
- **Returned in crop residue**
Partial N budgets for North America, billion lb
(average of 1998-2000)

<table>
<thead>
<tr>
<th></th>
<th>US</th>
<th>Canada</th>
<th>NA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Applied fertilizer</td>
<td>24.7</td>
<td>3.64</td>
<td>28.3</td>
</tr>
<tr>
<td>Recoverable manure</td>
<td>2.6</td>
<td>0.28</td>
<td>2.90</td>
</tr>
<tr>
<td>N fixation</td>
<td>15.6</td>
<td>1.41</td>
<td>17.0</td>
</tr>
<tr>
<td>Crop removal</td>
<td>32.1</td>
<td>5.02</td>
<td>37.1</td>
</tr>
<tr>
<td>Balance (inputs-removal)</td>
<td>10.8</td>
<td>0.31</td>
<td>11.1</td>
</tr>
<tr>
<td>Removal to use ratio</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>with manure</td>
<td>0.75</td>
<td>0.94</td>
<td>0.77</td>
</tr>
<tr>
<td>Removal to use ratio</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>without manure</td>
<td>0.80</td>
<td>0.99</td>
<td>0.82</td>
</tr>
</tbody>
</table>

Crop removal = N removed in harvested portion of alfalfa, soybeans, peanuts, 49% of lentils, and 54% of dry peas; It was assumed that any fixed N not recovered in the harvested crop was countered by soil N taken up during the growing season.

Source: Plant Nutrient Use in North American Agriculture, PPI/PPIC/FAR Technical Bulletin 2002-1
Partial $P_2O_5$ budgets for North America, billion lb (average of 1998-2000)

<table>
<thead>
<tr>
<th></th>
<th>US</th>
<th>Canada</th>
<th>N.A.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Applied fertilizer</td>
<td>8.8</td>
<td>1.51</td>
<td>10.3</td>
</tr>
<tr>
<td>Recoverable manure</td>
<td>3.3</td>
<td>0.4</td>
<td>3.7</td>
</tr>
<tr>
<td>Crop removal</td>
<td>11.4</td>
<td>1.87</td>
<td>13.3</td>
</tr>
<tr>
<td>Balance (inputs-removal)</td>
<td>0.7</td>
<td>0.04</td>
<td>0.7</td>
</tr>
<tr>
<td>Removal to use ratio with manure</td>
<td>0.95</td>
<td>0.98</td>
<td>0.95</td>
</tr>
<tr>
<td>Removal to use ratio without manure</td>
<td>1.3</td>
<td>1.24</td>
<td>1.29</td>
</tr>
</tbody>
</table>

Source: Plant Nutrient Use in North American Agriculture, PPI/PPIC/FAR Technical Bulletin 2002-1
Partial $K_2O$ budgets for North America, billion lb (average of 1998-2000)

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<thead>
<tr>
<th></th>
<th>US</th>
<th>Canada</th>
<th>N.A.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Applied fertilizer</td>
<td>10.1</td>
<td>0.78</td>
<td>10.9</td>
</tr>
<tr>
<td>Recoverable manure</td>
<td>3.8</td>
<td>0.5</td>
<td>4.3</td>
</tr>
<tr>
<td>Crop removal</td>
<td>19.3</td>
<td>2.64</td>
<td>21.9</td>
</tr>
<tr>
<td>Balance (inputs-removal)</td>
<td>-5.4</td>
<td>-1.36</td>
<td>-6.7</td>
</tr>
<tr>
<td>Removal to use ratio with manure</td>
<td>1.39</td>
<td>2.06</td>
<td>1.44</td>
</tr>
<tr>
<td>Removal to use ratio without manure</td>
<td>1.91</td>
<td>3.40</td>
<td>2.02</td>
</tr>
</tbody>
</table>

Source: Plant Nutrient Use in North American Agriculture, PPI/PPIC/FAR Technical Bulletin 2002-1
Partial budgets for six leading corn states, billion lb (average of 1998-2000)

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>P₂O₅</th>
<th>K₂O</th>
</tr>
</thead>
<tbody>
<tr>
<td>Applied fertilizer</td>
<td>8.8</td>
<td>3.0</td>
<td>4.1</td>
</tr>
<tr>
<td>Recoverable manure</td>
<td>0.5</td>
<td>0.9</td>
<td>1.0</td>
</tr>
<tr>
<td>N Fixation</td>
<td>8.4</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Crop removal</td>
<td>14.5</td>
<td>5.1</td>
<td>6.6</td>
</tr>
<tr>
<td>Balance (inputs-removal)</td>
<td>3.3</td>
<td>-1.3</td>
<td>-1.5</td>
</tr>
</tbody>
</table>

Removal to use ratio
with manure 0.82 1.33 1.30
Removal to use ratio
without manure 0.84 1.71 1.62

Source: Plant Nutrient Use in North American Agriculture, PPI/PPIC/FAR Technical Bulletin 2002-1
Ratio of P and K removal to fertilizer use plus manure nutrients applied to corn, soybeans, wheat, and cotton in the U.S.

Source: Plant Nutrient Use in North American Agriculture, PPI/PPIC/FAR Technical Bulletin 2002-1
NuGIS
Nutrient Use Geographic Information System

• Project is about mapping and spatial analysis of nutrient use data.
  – Initially sponsored by the PPI/TFI Nutrient Use Task Force
    then continued by IPNI
• Phase I: discovery of data sets and sample analysis
• Phase II: focused on national net nutrient budgets at the county and watershed levels.
Ratio of nutrient removed by crops to fertilizer nutrient applied plus nutrients in recoverable manure.

Legend for maps to follow

Removal/Use Ratio

- 0.00 - 0.30: Crop removal is less than fertilizer use, building soil fertility
- 0.31 - 0.50
- 0.51 - 0.70
- 0.71 - 0.90
- 0.91 - 1.09
- 1.10 - 2.00
- 2.01 - 3.00
- 3.01 - 6.00
- 6.01 - 12.00
- > 12.0: Crop removal is greater than fertilizer use, depleting soil fertility

Balanced budget (removal = use)
Estimated Nutrient Removal to Use by Watershed

Nutrient Removal by Crops(adj) / (Fertilizer + Recoverable Manure Nutrients + Legume N Fixation)

Use > Removal
Removal = Use
Removal > Use

Sources: State Boundaries: ESRI; Watershed Region, USGS; Fertilizer estimated using data from: AAPFCO 1987-2007, Crop Removal and Recoverable Manure Nutrients of Agriculture 1987-2007 USDA/NASS, NASS Quick Stats, 1986-2008 USDA/NASS, and Various State and regional NASS/ERS/Crop estimates from IPNI. Nutrient Removal based on detailed analysis of 21 Crops (corn, alfalfa, and peanuts) considered equivalent to 100% of these crops' Nitrogen Removal. Nutrient Removal values are adjusted by state for % of removal represented.

Map Produced By PAQ Interactive, for IPNI, July 2009
Estimated Nutrient Removal to Use by Hydrologic Region

Nutrient Removal by Crops(adj) / (Fertilizer + Recoverable Manure Nutrients)

P

US = 0.92

1.10 - 1.44

0.21 - 0.29

P2O5 Removal / Use
PRat2007

0.21 - 0.30
0.31 - 0.45
0.46 - 0.60
0.61 - 0.75
0.76 - 0.90
0.91 - 1.09
> 1.09

Estimated Nutrient Removal to Use by Watershed

Nutrient Removal by Crops(adj) / (Fertilizer + Recoverable Manure Nutrients)

P removal exceeds use in much of the Corn Belt

Use > Removal (excess P)

Removal = Use

Removal > Use (mining P)
K removal exceeds use but soil levels are generally very high.

K removal exceeds use by 10-20% in the western Corn Belt.
Fertilizer consumption in the U.S., 1955-2009

Data Source: AAPFCO (2008) and H. Vroomen, TFI (est. 2008-09)
A closer look at where we were in North America before use reductions (using NASS, AAPFCO, and the Ag Census data)

- Soils do not create P or K nutrients
- They have an indigenous amount and store what is added to them
- In a sustainable agriculture, the P and K removed by crops must eventually be replaced
Change in annual crop removal over 20 yrs, short tons

K₂O: 1986-88
7.4 million tons

P₂O₅: 1986-88
4.3 million tons

K₂O: 2006-08
9.5 million tons

P₂O₅: 2006-08
6.1 million tons
Nutrient removal by crops in the U.S.
(N removal by alfalfa, soybeans and peanuts excluded)

\[ y = 0.0866x - 164.9 \]

\[ y = 0.0706x - 133.4 \]

\[ y = 0.0548x - 104.8 \]

Annual increase: 1000 metric T  
55 71

1000 short T  
60 78
Nutrient removal by crops (short tons)

K₂O: 2006-08
9.5 mil
Increasing at 78,000/yr

P₂O₅: 2006-08
6.1 mil
Increasing at 60,000/yr

Fertilizer nutrient sales

K₂O: 2007
5.1 mil
Increasing at 5,000/yr

P₂O₅: 2007
4.5 mil
Increasing at 22,000/yr
Comparison of nutrient removal by crops in the U.S. to nutrient applied as fertilizer and in recoverable manure (removal is average of 2006-2008; fertilizer use is from 2007)

Even with the assumption that all recoverable manure P and K is applied where it is needed, the P budget is barely balanced and the K budget remains extremely negative.

* Based on 2007 livestock census using Kellogg et al. (2000) procedure.
Changes in Corn Belt P and K Budgets

Removal/Use

K-1987

Elimination of most of the K surpluses.

K-2007

P-1987

From P deficits and surpluses to mostly deficits.

P-2007

Green = excess nutrients  Red = depleting nutrients
Changes in state or province soil fertility levels from 2001 to 2005

2005 Median P
31 ppm

2005 Median K
154 ppm

- Corn Belt changes from 2005 to 2010?
  - Indications are that soil levels will be lower
  - More fields will require annual P and K fertilization
  - P and K agronomic demand should increase
Fertilizer consumption in the U.S., 1955-2009

Data Source: AAPFCO (2008) and H. Vroomen, TFI (est. 2008-09)
Agronomic implications of recent P and K use reductions?

- Loss of crop yields and profits?
- Depletion of soil nutrient reserves?
- Negative nutrient budgets?
2009 US Corn Yield Forecast at 161.9 bu/A
... a New Record

\[ y = 1.8658x - 3595 \]
\[ r^2 = 0.87 \]

In spite of large K and P fertilizer use reductions

USDA-NASS, 8/2009.
# Lots of calibration data in North America

Table 1. Soil test phosphorus calibration examples (Bray P1 except where noted).

<table>
<thead>
<tr>
<th>Soil test level (ppm)</th>
<th>Average Relative Yield (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>maize Iowa</td>
</tr>
<tr>
<td>2.5</td>
<td>66.5</td>
</tr>
<tr>
<td>5.0</td>
<td>77.3</td>
</tr>
<tr>
<td>7.5</td>
<td>86.7</td>
</tr>
<tr>
<td>10.0</td>
<td>91.3</td>
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<tr>
<td>12.5</td>
<td>94.1</td>
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<tr>
<td>15.0</td>
<td>95.9</td>
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<tr>
<td>17.5</td>
<td>97.1</td>
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<td>20.0</td>
<td>98.0</td>
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<td>22.5</td>
<td>98.7</td>
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<td>25.0</td>
<td>99.3</td>
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<td>27.5</td>
<td>99.6</td>
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<tr>
<td>30.0</td>
<td>99.8</td>
</tr>
<tr>
<td>32.5</td>
<td>99.9</td>
</tr>
<tr>
<td>35.0</td>
<td>100.0</td>
</tr>
</tbody>
</table>

*Olsen P, +Calculated from Bray P1 assuming Olsen P = 0.75 Bray P1.

Data: Potash & Phosphate Institute, PKMAN: A tool for personalizing P and K management. Version 1.0. Potash & Phosphate Institute, Norcross, GA.
MEY concept illustrates the impact of reduced application ...
MEY concept illustrates the impact of reduced application ... impact depends where you are on the yield curve.
Impacts of historical K management

1974 – 1984: Ample P + 56 kg K₂O/ha/yr

Ample P and K

Randall et al., 1997a,b
Soil tests vary in their background noise

Phosphorus

Potassium

Observed

Calculated

Soil nutrient supply

Time

Soil nutrient supply

Time
P removal to use ratios for the “I” states

Median Bray P, ppm
- 2001: IA 25, IL 36, IN 33
- 2005: IA 25, IL 36, IN 29
### P budgets for Iowa, Illinois, and Indiana per acre planted to principle crops

<table>
<thead>
<tr>
<th></th>
<th>IA</th>
<th>IL</th>
<th>IN</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fertilizer applied (2007)</strong></td>
<td>+</td>
<td>30</td>
<td>29</td>
</tr>
<tr>
<td><strong>Recoverable manure (2007)</strong></td>
<td>+</td>
<td>12</td>
<td>3</td>
</tr>
<tr>
<td><strong>Crop removal (avg of 06/07/08)</strong></td>
<td>-</td>
<td>53</td>
<td>52</td>
</tr>
<tr>
<td><strong>Balance</strong></td>
<td>=</td>
<td>-11</td>
<td>-20</td>
</tr>
</tbody>
</table>

*Based on avg of 2006-2008 acreage.

**Typical Bray1 or Mehlich 3 decline†, ppm:**

If continued for 5 years:

<table>
<thead>
<tr>
<th></th>
<th>IA</th>
<th>IL</th>
<th>IN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median soil test levels in 2005, ppm</td>
<td>25</td>
<td>36</td>
<td>29</td>
</tr>
</tbody>
</table>

†Assuming 18 lb P₂O₅/ppm.
P budgets for Iowa, Illinois, and Indiana per acre planted to principle crops with no P fertilizer

<table>
<thead>
<tr>
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<th>IL</th>
<th>IN</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>lb P\textsubscript{2}O\textsubscript{5}/A\textsuperscript{*}</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fertilizer applied (none)</td>
<td>+</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Recoverable manure (2007)</td>
<td>+</td>
<td>12</td>
<td>3</td>
</tr>
<tr>
<td>Crop removal (avg of 06/07/08)</td>
<td>-</td>
<td>53</td>
<td>52</td>
</tr>
<tr>
<td>Balance</td>
<td>=</td>
<td>-41</td>
<td>-49</td>
</tr>
</tbody>
</table>

*Based on avg of 2006-2008 acreage.

Typical Bray1 or Mehlich 3 decline\textsuperscript{†}, ppm:

\[
\begin{array}{ccc}
\text{2.3} & \text{2.7} & \text{2.2} \\
\text{If continued for 5 years:} & \text{12} & \text{14} & \text{11} \\
\end{array}
\]

Median soil test levels in 2005, ppm:

\[
\begin{array}{ccc}
\text{25} & \text{36} & \text{29} \\
\end{array}
\]

\textsuperscript{†}Assuming 18 lb P\textsubscript{2}O\textsubscript{5}/ppm.
### K budgets for Iowa, Illinois, and Indiana per acre planted to principle crops

<table>
<thead>
<tr>
<th></th>
<th>IA</th>
<th>IL</th>
<th>IN</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lb K₂O/A</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fertilizer applied</td>
<td>+ 42</td>
<td>49</td>
<td>60</td>
</tr>
<tr>
<td>(2007)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recoverable manure</td>
<td>+ 15</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>(2007)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crop removal</td>
<td>- 61</td>
<td>54</td>
<td>53</td>
</tr>
<tr>
<td>(avg of 06/07/08)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Balance</strong></td>
<td>= -5</td>
<td>-1</td>
<td>+15</td>
</tr>
</tbody>
</table>

*Based on avg of 2006-2008 acreage.

**Typical soil test K change**, ppm:
- If continued for 5 years:
  - IA: -3
  - IL: -1
  - IN: +9

**Median soil test levels in 2005, ppm**
- IA: 172
- IL: 178
- IN: 144

†Assuming 8 lb K₂O/ppm.
K budgets for Iowa, Illinois, and Indiana per acre planted to principle crops with no K fertilizer

<table>
<thead>
<tr>
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<th>IN</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lb K$_2$O/A</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fertilizer applied (none)</td>
<td>+</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Recoverable manure (2007)</td>
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<td>15</td>
<td>4</td>
</tr>
<tr>
<td>Crop removal (avg of 06/07/08)</td>
<td>-</td>
<td>61</td>
<td>54</td>
</tr>
<tr>
<td><strong>Balance</strong></td>
<td>=</td>
<td>-47</td>
<td>-50</td>
</tr>
</tbody>
</table>

*Based on avg of 2006-2008 acreage.

**Typical soil test K change†, ppm:**

-6    -6    -6

If continued for 5 years:

-30   -32   -28

**Median soil test levels in 2005, ppm**

172   178   144

†Assuming 8 lb K$_2$O/ppm.
Nutrient reduction impact on soil test levels and yield ... based on a budget approach

- May see little impact on soil test levels after one year of reduced rates
- May see little negative impact on yield if soil test levels are above the critical level
Summary

• Nutrient budgets are important to farmers and to society ... they are indicators of sustainability.

• Weaknesses exist in our current capacity to accurately evaluate nutrient budgets at appropriate resolution:
  – Crop nutrient removal coefficients
  – Census data for specific nutrient use expenditures
  – AAPFCO county level fertilizer sales data
Summary

• Crop nutrient removal is increasing faster than nutrient use nationally and in most key production areas.

• Most of the Corn Belt appears to be mining soil P and many areas appear also to be mining soil K ...

intensive monitoring of soil fertility is a critical BMP.