Chapter 13: Nutrient Management

The law of the Minimum?

The capacity of a barrel made of many wooden staves of different lengths is limited by the shortest piece.
Main Objectives

1. Fully understand why do we manage soil fertility.
2. Clearly knows what are involved in soil sampling.
3. Capable of explaining Liebig's law of the minimum and putting it into practice.
4. Understand the potential and the limitation of soil testing and plant tissue analysis
5. Knows common chemical fertilizers and their applications
6. Knows the pros and cons of common recycled organic fertilizers.
7. Have a systematic view for achieving high fertilizer efficiency.
Key Terms and Concepts

1. Liebig's law of the minimum.

2. Chemical fertilizer grade

3. Critical nutrient range (CNR) or threshold values

4. Fertilizer-induced soil acidity
Why do we manage soil fertility?

1. Yield
2. Costs
3. Product quality
4. Environmental pollution
5. Where do BMPs come from?
Human-Caused Global Nitrogen Emissions

- Ammonia ($\text{NH}_3$)
- Nitric oxide (NO)
- Nitrous oxide ($\text{N}_2\text{O}$)
Figure 4. Relationship between sewer population and nitrogen fluxes due to sewage wastewater. The regression line indicates a per capita load in wastewater of 3.1 kg N yr$^{-1}$ per person.

16 watersheds in Northeastern US
Soil Sampling

1. How deep should we sample?
2. How many cores per composite sample?
3. How frequent?
4. What should be the exact sampling location in a field (on the row or between-rows?)
5. How to deal with field heterogeneity?
6. History matters too.
Figure 13.23

*PSNT: Pre-sidedress Soil Nitrate Test
Determining which fertilizers are needed. Plant response trials, showing example plot layouts and plant responses. (A) A simple test, showing a need for N. (B) A subtractive trial, useful when deficiencies may be multiple, showing a need for both N and P. (C) A factorial trial, used mainly for defining interactions.
Soil tests and recommendations

(1) Justus Liebig's law of the minimum: the growth of any plant is limited most by the essential plant growth factor that presents in the least relative amount.

(2) Individual Tests:
(Please read the text on this topic and gain a general understanding on it.)

First of all, pH, soluble salts, and lime requirement are easily done and widely used. Tests of other nutrients are more expensive or less reliable for practical purposes. Very often soil tests are used for diagnostic reasons, and mostly in combination with field trials.

pH/Acidity: please refer to the chapter on chemical properties
Soluble Salts: by conductivity
N: NO₃⁻?  Little practical value
P: using weak acids or bicarbonate for soils with pH>8.5
K: soluble and exchangeable
The law of the minimum and the limiting factor

Figure 13.18
Both too little and too much of a nutrient supply could be a limiting factor (V. E. Shelford 1913). The success of an organism, population, or community depends on a complex of conditions; any condition that approaches or exceeds the limit of tolerance may be said to be a limiting factor.
Figure 13.25

The figure depicts a scatter plot showing the relationship between soil test results and profit or loss, with a trend line indicating the cost of fertilization and potential pollution or toxicity problems. The x-axis represents soil test result categories ranging from very low to very high to excessive, while the y-axis shows the value of yield increase or loss. The data points suggest a decreasing trend as soil test results increase, highlighting the economic implications of different soil conditions.
Figure 13.28 The generalized relationship between levels of plant-available phosphorus in soils (soil test P level) and environmental losses of P dissolved in surface runoff and subsurface drainage waters. The generalized relationship between traditional plant nutrient supply interpretation categories and environmental interpretation categories is also indicated. The diagram suggests that, fortunately, soil P levels can be achieved that are both conducive to optimum plant growth and protective of the environment. If P losses by soil erosion are controlled (although not shown, this is a big if), significant quantities of dissolved P would be lost only when soils contain P levels in excess of those needed for optimum plant growth. Losses of P by leaching in drainage water would be significant only at very high soil P levels, as this pathway rapidly increases only after the P-sorption capacity of the soil is substantially saturated. Note the threshold levels (vertical arrows) for P losses. The vertical axes are not to scale. [Figure based on data and concepts discussed in Sharples (1997), Beegle et al. (2000), and Higgs et al. (2000)]
Analysis of plant tissues

(1) Nutrients in the soil may not be taken up by plants for some reasons (e.g., low soil temperature, plants grow too fast, soil is too dry, not enough oxygen, root damage).

(2) Critical nutrient range or threshold values

(3) Visual nutrient deficiency symptoms
   Please note that the mobility of each nutrient matters
   Symptoms varies with different plant species
Common chemical fertilizers

(1) Grade (percent w/w)
   \% N as pure N
   \% P as P\textsubscript{2}O\textsubscript{5}
   \% K as K\textsubscript{2}O

(2) Acidity of chemical fertilizers, for example:

\[
\text{NH}_4^+ + O_2 \rightarrow \text{NO}_3^- + 2\text{H}^+ + \text{H}_2\text{O}
\]

(3) Calculations in using fertilizers

From needed amount to the actual amount of a particular fertilizer
## Significant Acidification in Major Chinese Croplands

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Table 1. Topsoil pH changes in major Chinese croplands between the 1980s and 2000s. The soil groups are defined in (13). NS, not significant; pH range is an average (5 to 95 percentile).

<table>
<thead>
<tr>
<th>Soil group</th>
<th>Sample number</th>
<th>pH value</th>
<th>1980s</th>
<th>Cereal crop systems*</th>
<th>2000s</th>
<th>Cash crop systems†</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Sample number</td>
<td>pH value</td>
<td>pH change</td>
<td>Sample number</td>
</tr>
<tr>
<td>I</td>
<td>301</td>
<td>5.37</td>
<td>(4.40–6.60)</td>
<td>505</td>
<td>5.14 (4.17–6.52)</td>
<td>−0.23‡</td>
</tr>
<tr>
<td>II</td>
<td>1157</td>
<td>6.33</td>
<td>(5.00–8.04)</td>
<td>1101</td>
<td>6.20 (5.00–7.70)</td>
<td>−0.13‡</td>
</tr>
<tr>
<td>III</td>
<td>297</td>
<td>6.42</td>
<td>(4.50–8.30)</td>
<td>211</td>
<td>5.66 (4.27–8.06)</td>
<td>−0.76‡</td>
</tr>
<tr>
<td>IV</td>
<td>562</td>
<td>6.32</td>
<td>(5.10–7.89)</td>
<td>537</td>
<td>6.00 (4.84–7.60)</td>
<td>−0.32‡</td>
</tr>
<tr>
<td>V</td>
<td>995</td>
<td>7.96</td>
<td>(6.39–8.80)</td>
<td>850</td>
<td>7.69 (5.37–8.70)</td>
<td>−0.27‡</td>
</tr>
<tr>
<td>VI</td>
<td>493</td>
<td>8.16</td>
<td>(7.10–8.80)</td>
<td>250</td>
<td>8.16 (7.49–8.82)</td>
<td>−0.00 (ns)</td>
</tr>
</tbody>
</table>

*Cereal/fiber crops (such as rice, wheat, maize, and cotton). †High-input cash crops (such as vegetables, fruit trees, and tea). ‡P < 0.001.
**Acidifying from N-fertilization:** $\text{NH}_4^+ + \text{O}_2 \rightarrow \text{NO}_3^- + \text{H}^+$

**Fig. 3.** $\text{H}^+$ production budget of main factors in four typical Chinese cropping systems. W-M, wheat-maize; R-W, rice-wheat; R-R, rice-rice; and G-V, greenhouse vegetables. N cycling, S uptake, and P uptake denote the $\text{H}$ produced by N cycling and S and P uptake processes. BCs uptake indicates $\text{H}$ released by BCs uptake. Net $\text{H}$ production is the algebraic sum of $\text{H}$ resulting from N cycling and P, S, and BCs uptake. Data are means ± SD. (From: J H Guo et al. 2010, *Science* **327**:1008)
Figure 13.1
<table>
<thead>
<tr>
<th>Crop</th>
<th>Yield/Acre</th>
<th>( N )</th>
<th>( P )</th>
<th>( K )</th>
<th>( Ca )</th>
<th>( Mg )</th>
<th>( S )</th>
<th>( Cu )</th>
<th>( Mn )</th>
<th>( Zn )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alfalfa</td>
<td>6 tons</td>
<td>350</td>
<td>40</td>
<td>300</td>
<td>160</td>
<td>40</td>
<td>44</td>
<td>0.10</td>
<td>0.64</td>
<td>0.62</td>
</tr>
<tr>
<td>Apples</td>
<td>500 bu</td>
<td>30</td>
<td>10</td>
<td>45</td>
<td>8</td>
<td>5</td>
<td>10</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>Barley (grain)</td>
<td>60 bu</td>
<td>65</td>
<td>14</td>
<td>24</td>
<td>2</td>
<td>6</td>
<td>8</td>
<td>0.04</td>
<td>0.03</td>
<td>0.08</td>
</tr>
<tr>
<td>Bean (dry, seed)</td>
<td>30 bu</td>
<td>75</td>
<td>25</td>
<td>25</td>
<td>2</td>
<td>2</td>
<td>5</td>
<td>0.02</td>
<td>0.03</td>
<td>0.06</td>
</tr>
<tr>
<td>Bluegrass</td>
<td>2 tons</td>
<td>60</td>
<td>12</td>
<td>55</td>
<td>16</td>
<td>7</td>
<td>5</td>
<td>0.02</td>
<td>0.30</td>
<td>0.08</td>
</tr>
<tr>
<td>Cabbage</td>
<td>20 tons</td>
<td>130</td>
<td>35</td>
<td>130</td>
<td>20</td>
<td>8</td>
<td>44</td>
<td>0.04</td>
<td>0.10</td>
<td>0.08</td>
</tr>
<tr>
<td>Canola</td>
<td>45 bu</td>
<td>145</td>
<td>32</td>
<td>100</td>
<td>—</td>
<td>—</td>
<td>28</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Coastal Bermudagrass</td>
<td>8 tons</td>
<td>400</td>
<td>45</td>
<td>310</td>
<td>48</td>
<td>32</td>
<td>32</td>
<td>0.02</td>
<td>0.64</td>
<td>0.48</td>
</tr>
<tr>
<td>Corn (grain)</td>
<td>200 bu</td>
<td>150</td>
<td>40</td>
<td>40</td>
<td>6</td>
<td>18</td>
<td>15</td>
<td>0.08</td>
<td>0.10</td>
<td>0.18</td>
</tr>
<tr>
<td>Corn (stover)</td>
<td>6 tons</td>
<td>110</td>
<td>12</td>
<td>160</td>
<td>16</td>
<td>36</td>
<td>16</td>
<td>0.05</td>
<td>1.50</td>
<td>0.30</td>
</tr>
<tr>
<td>Cotton (seed+lint)</td>
<td>1.3 tons</td>
<td>63</td>
<td>25</td>
<td>31</td>
<td>4</td>
<td>7</td>
<td>5</td>
<td>0.18</td>
<td>0.33</td>
<td>0.96</td>
</tr>
<tr>
<td>Oats (grain)</td>
<td>80 bu</td>
<td>60</td>
<td>10</td>
<td>15</td>
<td>2</td>
<td>4</td>
<td>6</td>
<td>0.03</td>
<td>0.12</td>
<td>0.05</td>
</tr>
<tr>
<td>Oats (straw)</td>
<td>2 tons</td>
<td>35</td>
<td>8</td>
<td>90</td>
<td>9</td>
<td>12</td>
<td>9</td>
<td>0.03</td>
<td>—</td>
<td>0.29</td>
</tr>
<tr>
<td>Onion</td>
<td>7.5 tons</td>
<td>45</td>
<td>20</td>
<td>40</td>
<td>11</td>
<td>2</td>
<td>18</td>
<td>0.03</td>
<td>0.08</td>
<td>0.31</td>
</tr>
<tr>
<td>Peanut (nuts)</td>
<td>2 tons</td>
<td>140</td>
<td>22</td>
<td>35</td>
<td>6</td>
<td>5</td>
<td>10</td>
<td>0.04</td>
<td>0.30</td>
<td>0.25</td>
</tr>
<tr>
<td>Potato (white, tuber)</td>
<td>15 tons</td>
<td>90</td>
<td>48</td>
<td>158</td>
<td>5</td>
<td>7</td>
<td>7</td>
<td>0.06</td>
<td>0.14</td>
<td>0.08</td>
</tr>
<tr>
<td>Sorghum (grain)</td>
<td>80 bu</td>
<td>65</td>
<td>30</td>
<td>22</td>
<td>4</td>
<td>7</td>
<td>10</td>
<td>0.02</td>
<td>0.06</td>
<td>0.05</td>
</tr>
<tr>
<td>Sorghum-sudangrass</td>
<td>8 tons</td>
<td>320</td>
<td>55</td>
<td>400</td>
<td>—</td>
<td>47</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Soybean (grain)</td>
<td>50 bu</td>
<td>188</td>
<td>41</td>
<td>74</td>
<td>19</td>
<td>10</td>
<td>23</td>
<td>0.05</td>
<td>0.06</td>
<td>0.05</td>
</tr>
<tr>
<td>Sugarcane</td>
<td>40 tons</td>
<td>180</td>
<td>41</td>
<td>250</td>
<td>—</td>
<td>25</td>
<td>22</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Tomato</td>
<td>20 tons</td>
<td>120</td>
<td>40</td>
<td>160</td>
<td>7</td>
<td>11</td>
<td>14</td>
<td>0.07</td>
<td>0.13</td>
<td>0.16</td>
</tr>
<tr>
<td>Wheat (grain)</td>
<td>60 bu</td>
<td>70</td>
<td>20</td>
<td>25</td>
<td>2</td>
<td>10</td>
<td>4</td>
<td>0.04</td>
<td>0.10</td>
<td>0.16</td>
</tr>
</tbody>
</table>


*For kg/ha, multiply lb/acre by 1.12. Weight (lb) per bushel (bu) of apples, 42; barley, 48; canola, 50; corn, 56; oats, 32; sorghum, 56; soybeans, 60; wheat, 60.*
Applying chemical fertilizers

- Starter
- Broadcast (Topdressing)
- Point injector
- Deep banding
- Split application
- Side-dressing
- Fertigation
- Foliar sprays
- Paddy soils
Organic fertilizers from recycled sources or by-products

(1) Types commonly available
The quality of each kind is not always consistent (Table 13.4).

(2) Rates of release (Table 13.5; Fig. 13.15)
Only a portion of the nutrients in organic fertilizers may be immediately available.

(3) Pros and cons of recycled organic fertilizers vs. synthetic ones
FIGURE 16–5  Sewage sludge is mostly liquid. The solid portion is mostly organic. The small inorganic part is most limiting to sludge usefulness because it often contains many toxic elements.

Singer & Munns 1999
Cover crops can substantially reduce the concentration of nitrate-N in winter drainage water by soaking up excess mineral nitrogen left in the soil after the summer crop is harvested. In the case illustrated, the cover crops were grown from September through November following the harvest of sweet corn. The data show averages for 2 years and two sites in Quebec, Canada. Both sites had fine-textured soils in the Inceptisols order. Among the cover crops, red clover was the least effective in reducing nitrogen leaching, partly because it produced the least growth and partly because it is a nitrogen-fixing legume that is relatively inefficient at scavenging leftover nitrogen. [Data from Isse et al. (1999)]
About fertilizer use efficiency

Utilization efficiency vs. economic efficiency:
Utilization Efficiency is defined as the percentage of added fertilizer that is actually used by the plants. While Economic Efficiency is often measured by the change of economic return (often in terms of dollar amount) after fertilization, or economic margins. The two do not necessarily go side-by-side.

Some guidelines for achieving high utilization efficiency:
- First, please use the "Law of the minimum."
- Second, understand the concept of factor interactions.
- Third, maximize recycling.
- Fourth, budgeting—a balance of input with output.
- Fifth, timing and system dynamics.

For example,
- Avoid single, large dose of N and P, why?
- What's in the consideration of timing?
- The interactions between water, O₂, and root growth?

9. Precision Agriculture

It has been given high hopes by the techno-dependent people.
From Brady & Weil 14th Ed. Figure 16.41

The diagram illustrates the relationship between fertilizer added (kg/ha) and profit. The y-axis represents the increase in crop yield from fertilizers (Mg/ha), while the x-axis shows the fertilizer added (kg/ha). The shaded area represents profit, with maximum profit and maximum yield marked on the graph. The figure also highlights the increase in crop yield and value as fertilizers are added.
Crop rotation can increase yields and reduce fertilizer requirements. (a) The amount of fertilizer nitrogen required (≠) for high corn yields was less than 50 kg N/ha in the corn–soybean rotation (solid line), but over 150 kg N/ha in the continuous corn system (dashed line). These soils supported either corn every year or corn every second year alternating with soybeans for the 12 years. The rotation corn maintained some yield advantage even when high amounts of nitrogen were applied, indicating that in addition to increased nitrogen availability after soybeans, the crop rotation conferred other benefits, such as pest reduction or improved soil microbial activity. Crop rotations involving more than two crops usually produce even greater benefits, especially if several years in the rotation are devoted to perennial grass-legume hay or pasture. (b) The use of isotopically labeled fertilizer (15NH4NO3) showed that even when a relatively high rate was applied (168 kg N/ha), most of the corn’s N needs came not directly from the fertilizer, but from the mineralization of soil organic matter. This was especially true in the latter part of the growing season. By harvest time, the fertilizer-derived nitrogen taken up by the corn represented less than one-third of the nitrogen taken up by the plants, and accounted for less than one-third of the fertilizer nitrogen applied to the soil. Corn grown in rotation with soybeans (not shown) took up more nitrogen from both soil and fertilizer sources than did corn grown after corn. These data are averages for 2 years and two soils (a silt loam Ustoll and a loam Udoll) in Kansas, but the results are typical of those found in many parts of the world (compare Table 14.10). [Data recalculated from Omay et al. (1998)]
Figure 13.8 Effects of winter cover crops and inorganic fertilizer on the yield of the following main crop of processing tomatoes grown on a Xeralf soil in California. The amount of nitrogen shown on the x-axis was added either as inorganic fertilizer or as aboveground residues of the cover crops, or a combination of both. Note that nitrogen from either source seemed to be equally effective. For tomato, which requires nitrogen over a long period of time, vetch alone or vetch mixed with oats produced enough nitrogen for near-optimal yields. [Data abstracted from Stivers et al. (1993) ©Lewis Publishers, an imprint of CRC Press, Boca Raton, Florida]
<table>
<thead>
<tr>
<th>Inputs and outputs</th>
<th>Western Kenya</th>
<th>North China</th>
<th>Midwest U.S.A</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>P</td>
<td>N</td>
</tr>
<tr>
<td>Fertilizer</td>
<td>7</td>
<td>8</td>
<td>588</td>
</tr>
<tr>
<td>Biological N fixation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total agronomic inputs</td>
<td>7</td>
<td>8</td>
<td>588</td>
</tr>
<tr>
<td>Removal in grain and/or beans</td>
<td>23</td>
<td>4</td>
<td>361</td>
</tr>
<tr>
<td>Removal in other harvested products</td>
<td>36</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Total agronomic outputs</td>
<td>59</td>
<td>7</td>
<td>361</td>
</tr>
<tr>
<td>Agronomic inputs minus harvest removals</td>
<td>-52</td>
<td>+1</td>
<td>+227</td>
</tr>
</tbody>
</table>

Inputs and outputs of nitrogen and phosphorus by managed pathways in a low-input corn-based system in Western Kenya in 2004–2005 (8), a highly fertilized wheat-corn double-cropping system in North China (2003–2005) (9–11), and a tile-drained corn-soybean rotation in Illinois, USA (1997–2006) (14). Potential crop yields are similar in these systems, but realized yields of corn were 2000, 8500, and 8200 kg ha\(^{-1}\) year\(^{-1}\) per crop in the Kenya, China, and U.S. systems, respectively. Wheat yielded another 5750 kg ha\(^{-1}\) year\(^{-1}\) in China, and soybeans yielded 2700 kg ha\(^{-1}\) year\(^{-1}\) every other year in Illinois. (Because the Illinois system represents a 2-year rotation, all nutrient inputs and removals were adjusted to place them on an annual basis.)

Vitousek et al., 2009. Science 324:1519-1520
Fig. 1 Broadbalk. Mean yields of wheat grain, and changes in husbandry

- Fungicides
- Herbicides
- Liming
- Fallowing
- Continuous wheat
- PK+144 kg N
- FYM+96 kg N
- Best NPK

Short-straw Cultivars

1840 1860 1880 1900 1920 1940 1960 1980 2000 2020
Red Rostock  Red Club  Sq. Master  Red Standard  Sq. Master  Flanders  Apollo  Cappelle D.  Brimstone  Hereward