Soil pH and Liming

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Soil Fertility Extension Specialist
Iowa State University
What Is pH?

- **Definition of pH**
  - Measure of acidity or alkalinity
  - Negative log of hydrogen ion concentration
  - As $H^+$ ion concentration increases, pH number decreases
  - One unit change in pH = 10 fold change in concentration of $H^+$ ions
Importance of soil pH

- Affects chemical and biological reactions
  - Availability of essential nutrients
    - Influences nutrient forms
  - Solubility (toxicity) of some elements (like Al)
  - Activity of microorganisms
  - Performance/carryover of some herbicides
How Soils Become Acidic

- Nitrification of ammonium
- Bases removed by crops
- Bases removed by leaching
- Acidic parent material
  - Carbonic acid from microbial and plant respiration
  - Organic acids secreted by plant roots
Limestone Needed to Offset Acidity from Nitrogen Fertilizers

<table>
<thead>
<tr>
<th>Nitrogen Source</th>
<th>Pound of Aglime per Pound of N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonium Sulfate</td>
<td>7</td>
</tr>
<tr>
<td>Ammonium Phosphates</td>
<td>7</td>
</tr>
<tr>
<td>Anhydrous Ammonia</td>
<td>4</td>
</tr>
<tr>
<td>UAN Solution</td>
<td>4</td>
</tr>
<tr>
<td>Urea</td>
<td>4</td>
</tr>
<tr>
<td>Ammonium Nitrate</td>
<td>4</td>
</tr>
</tbody>
</table>

Approximate amount. Adapted from Modern Corn Production.
### Amount of CaCO₃ Equivalent Needed to Replace Basic Cations in Crop Removal

<table>
<thead>
<tr>
<th>Crop</th>
<th>Yield per acre</th>
<th>lb Aglime per acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn Grain</td>
<td>150 bu</td>
<td>20</td>
</tr>
<tr>
<td>Corn Silage</td>
<td>8 ton</td>
<td>200</td>
</tr>
<tr>
<td>Oats</td>
<td>75 bu</td>
<td>5</td>
</tr>
<tr>
<td>Soybean</td>
<td>45 bu</td>
<td>95</td>
</tr>
<tr>
<td>Alfalfa</td>
<td>4 ton</td>
<td>515</td>
</tr>
</tbody>
</table>

Nature of Soil Acidity

- **Active acidity**
  - Free hydrogen ions in soil solution
    - Measured by soil water pH
    - Very small part of total acidity in soil
    - Would take less than 1/3 lb/acre limestone to neutralize
Nature of Soil Acidity

- **Reserve acidity**
  - Neutralizable H ions and Al in association with organic matter and clay
  - Accounts for virtually all of the total acidity in soil
  - This is what limestone must neutralize when acid soils are limed in order to increase pH
  - Estimated by buffer pH

\[ \text{Ca}^{++} \quad \text{Active Acidity} \]
\[ \text{K}^+ \quad \text{Soil Colloid} \]
\[ \text{Clay} \]
\[ \text{Humus} \]
\[ - \quad - \quad - \]
\[ \text{H}^+ \quad \text{H}^+ \quad \text{K}^+ \]
\[ \text{H}^+ \quad \text{K}^+ \quad \text{H}^+ \]
\[ \text{H}^+ \quad \text{Mg}^{++} \quad \text{H}^+ \]
\[ \text{H}^+ \quad \text{H}^+ \quad \text{K}^+ \]
\[ \text{Mg}^{++} \quad \text{K}^+ \quad \text{H}^+ \]
\[ \text{Ca}^{++} \quad \text{H}^+ \quad \text{Mg}^{++} \]
\[ \text{Reserve Acidity} \]
Chemical Soil Test Procedure

Soil Water pH

- Scoop 5-g soil sample
- Add 5 ml distilled water
- Stir for 5 sec.; Let Stand for 10 Min.
- Place pH electrodes in the slurry, swirl and read pH immediately
Chemical Soil Test Procedure

SMP or Sikora Buffer Lime Requirement

- Add 10 ml Buffer solution to the soil-water slurry saved from pH determination
- Shake for 10 min.; Let stand for 30 min.
- Swirl and read pH
  - Interested in the pH change from the initial buffer solution pH of 7.50
- Sikora buffer
  - New buffer used in Iowa (equivalent to SMP)
  - No hazardous chemicals

NCR Pub. 221
Determining Lime Requirement

- Measure "reserve" acidity to decide the lime amount to apply to raise pH to a given level

\[
\begin{align*}
\text{pH of Buffer Solution} & \rightarrow 7.5 \\
\text{pH of Buffer + Soil} & \rightarrow 6.3 \\
\text{Initial Soil pH} & \rightarrow 5.6
\end{align*}
\]

\{ Index of reserve soil acidity \}

Calibrated with field soil pH increase from lime application to determine amount of lime needed to increase pH to some level

Example
Clay Loam (CEC 20): Soil pH 5.6; Buffer pH 6.1
Sandy Loam (CEC 5): Soil pH 5.6; Buffer pH 6.8
Alkaline Soils

- Soil pH > 7.0
- CEC saturated with basic cations
- pH controlled by:
  - Dissolved carbon dioxide chemistry
  - Solid Ca and Mg carbonates (1 to 20% by wt.)
    - pH 7.2 to 8.5
  - Exchangeable Na and dissolution of Na$_2$CO$_3$
    - pH 8.5 to 10.5
Calcareous Soils

- Not economical to lower pH
  - All CaCO$_3$ must be dissolved before pH can be lowered
  - If soil contains 1% lime in top 7 inches
    - Would require 68 tons concentrated sulfuric acid to neutralize
- Bray P$_1$ test will give false low readings on some soils with pH above 7.4
  - Use Olsen bicarbonate extractant
  - Use Mehlich-3 extractant
How Lime Application Reduces Soil Acidity

- Ca\(^{++}\) and Mg\(^{++}\) from lime replaces two H\(^{+}\) ions on the cation exchange complex (reserve acidity)
- The H\(^{+}\) ions combine with OH\(^{-}\) (hydroxyl) ions to form water
- pH increases because the acidity source (H\(^{+}\)) has been reduced

\[
\text{CaCO}_3 + 2\text{H}^+ = \text{Ca}^{+2} + \text{CO}_2 \uparrow + \text{H}_2\text{O}
\]

\[
\text{MgCO}_3 + 2\text{H}^+ = \text{Mg}^{+2} + \text{CO}_2 \uparrow + \text{H}_2\text{O}
\]

J.E. Sawyer, ISU Agronomy Extension
Liming Rate

- Depends on amount of reserve acidity to neutralize
  - Soil pH and CEC (change in base saturation)
Limestone Quality Impacts

Application Rate

- **Calcium Carbonate Equivalent (CCE)**
  - Material in limestone that is effective in neutralizing acid
  - Ca and Mg carbonates

- **Particle size**

- **Both combined determine limestone quality**
  - **Effective Calcium Carbonate Equivalent (ECCE)**
How to Calculate Limestone Effective Calcium Carbonate Equivalent (ECCE)

<table>
<thead>
<tr>
<th>% of Particles Passing Each Screen</th>
<th>Fineness Factor</th>
<th>Percent Available Based on Fineness</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-mesh</td>
<td>100</td>
<td>x 0.1 = 10</td>
</tr>
<tr>
<td>8-mesh</td>
<td>90</td>
<td>x 0.3 = 27</td>
</tr>
<tr>
<td>60-mesh</td>
<td>55</td>
<td>x 0.6 = 33</td>
</tr>
<tr>
<td>Total Fineness Efficiency</td>
<td></td>
<td>70</td>
</tr>
</tbody>
</table>

Effective Calcium Carbonate Equivalent (ECCE):

\[
\text{(Total Fineness Efficiency ÷ 100) \times (\% \ CCE ÷ 100) \times ([100 - \% \ Moisture] ÷ 100) \times 2000} = \text{ECCE}
\]

Example:

\[
(70 ÷ 100) \times (92 ÷ 100) \times ([100 - 2] ÷ 100) \times 2,000 = 1,260 \text{ ECCE}
\]
Steps in Making Limestone Recommendations

- Check soil pH
  - Is lime needed?
- Determine CaCO$_3$ requirement
  - Use Buffer pH
- Adjust rate for limestone quality
  - lb ECCE per ton or %
- Adjust rate for incorporation depth
Suggested Soil pH Ranges for Different Crops

- Corn and soybean
  - pH 6.5 sufficient
  - (pH 6.0 sufficient for high pH subsoils)
- Alfalfa
  - pH 6.9 sufficient
- Grass pastures and grass hayland
  - pH 6.0 sufficient

Note: High pH subsoil means calcareous within a four-foot depth of the surface.
Corn & Soybean pH/Lime Updates

<table>
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<tr>
<th>Corn and Soybean</th>
<th>Lime if pH is</th>
<th>Raise to pH</th>
</tr>
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<tr>
<td>- High subsoil pH</td>
<td>&lt; 6.0 (no change)</td>
<td>6.0, not 6.5</td>
</tr>
<tr>
<td>- Low subsoil pH</td>
<td>&lt; 6.5 (no change)</td>
<td>6.5 (no change)</td>
</tr>
</tbody>
</table>

Iowa Soil Associations Areas with High subsoil-pH
- Clarion-Nicollet-Webster
- Galva-Primghar-Sac
- Ida-Monona
- Luton-Onawa-Salix
- Marshall
- Moody
Corn & Soybean soil pH/Lime Updates

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</tr>
<tr>
<td>- Low subsoil pH</td>
<td>&lt; 6.5 (no change)</td>
<td>6.5 (no change)</td>
</tr>
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14 Replicated Strip-Trials, Evaluated Four Years
3 ton ECCE/acre

Low pH Subsoil Association Areas
Averages Across Corn and Soybean

High pH Subsoil Association Areas
Averages Across Corn and Soybean

Pagani and Malarino, 2012
How to Calculate Limestone Requirement - Example

<table>
<thead>
<tr>
<th>Example</th>
<th>Corn - Soybean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil Test pH</td>
<td>5.7</td>
</tr>
<tr>
<td>Buffer pH</td>
<td>6.6</td>
</tr>
<tr>
<td>Target pH</td>
<td>6.5</td>
</tr>
<tr>
<td>Limestone ECCE</td>
<td>1,260 (63% or 0.63)</td>
</tr>
<tr>
<td>Six inch soil depth to neutralize</td>
<td></td>
</tr>
</tbody>
</table>

CaCO$_3$ rate from chart: 2,100 lb/acre

Correction for limestone quality: 2,100 lb/acre ÷ 0.63

Recommended lime rate: 3,300 lb/acre
Table 16. Lime recommendations based on SMP or Sikora buffer pH methods, given in pounds per acre of finely ground pure calcium carbonate (CaCO₃) to increase soil pH from its present level to pH 6.0, 6.5, or 6.9 for the soil depth to be neutralized.†

<table>
<thead>
<tr>
<th>Buffer pH</th>
<th>pH 6.0</th>
<th>pH 6.5</th>
<th>pH 6.9</th>
<th>pH 6.0</th>
<th>pH 6.5</th>
<th>pH 6.9</th>
<th>pH 6.0</th>
<th>pH 6.5</th>
<th>pH 6.9</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.0</td>
<td>0</td>
<td>0</td>
<td>400</td>
<td>0</td>
<td>0</td>
<td>600</td>
<td>0</td>
<td>0</td>
<td>1,100</td>
</tr>
<tr>
<td>6.9</td>
<td>0</td>
<td>0</td>
<td>600</td>
<td>0</td>
<td>0</td>
<td>1,000</td>
<td>0</td>
<td>0</td>
<td>1,900</td>
</tr>
<tr>
<td>6.8</td>
<td>0</td>
<td>200</td>
<td>900</td>
<td>0</td>
<td>300</td>
<td>1,400</td>
<td>0</td>
<td>600</td>
<td>2,700</td>
</tr>
<tr>
<td>6.7</td>
<td>0</td>
<td>400</td>
<td>1,200</td>
<td>0</td>
<td>700</td>
<td>1,800</td>
<td>0</td>
<td>1,300</td>
<td>3,500</td>
</tr>
<tr>
<td>6.6</td>
<td>0</td>
<td>700</td>
<td>1,500</td>
<td>0</td>
<td>1,100</td>
<td>2,200</td>
<td>0</td>
<td>2,100</td>
<td>4,400</td>
</tr>
<tr>
<td>6.5</td>
<td>100</td>
<td>900</td>
<td>1,700</td>
<td>100</td>
<td>1,400</td>
<td>2,600</td>
<td>200</td>
<td>2,800</td>
<td>5,200</td>
</tr>
<tr>
<td>6.4</td>
<td>300</td>
<td>1,200</td>
<td>2,000</td>
<td>400</td>
<td>1,800</td>
<td>3,000</td>
<td>800</td>
<td>3,500</td>
<td>6,000</td>
</tr>
<tr>
<td>6.3</td>
<td>500</td>
<td>1,400</td>
<td>2,300</td>
<td>700</td>
<td>2,100</td>
<td>3,400</td>
<td>1400</td>
<td>4,200</td>
<td>6,800</td>
</tr>
<tr>
<td>6.2</td>
<td>700</td>
<td>1,700</td>
<td>2,600</td>
<td>1000</td>
<td>2,500</td>
<td>3,900</td>
<td>2000</td>
<td>5,000</td>
<td>7,700</td>
</tr>
<tr>
<td>6.1</td>
<td>900</td>
<td>1,900</td>
<td>2,800</td>
<td>1300</td>
<td>2,900</td>
<td>4,300</td>
<td>2500</td>
<td>5,700</td>
<td>8,500</td>
</tr>
<tr>
<td>6.0</td>
<td>1000</td>
<td>2,200</td>
<td>3,100</td>
<td>1600</td>
<td>3,200</td>
<td>4,700</td>
<td>3100</td>
<td>6,400</td>
<td>9,300</td>
</tr>
<tr>
<td>5.9</td>
<td>1200</td>
<td>2,400</td>
<td>3,400</td>
<td>1900</td>
<td>3,600</td>
<td>5,100</td>
<td>3700</td>
<td>7,100</td>
<td>10,100</td>
</tr>
<tr>
<td>5.8</td>
<td>1400</td>
<td>2,600</td>
<td>3,700</td>
<td>2200</td>
<td>4,000</td>
<td>5,500</td>
<td>4300</td>
<td>7,900</td>
<td>11,000</td>
</tr>
<tr>
<td>5.7</td>
<td>1600</td>
<td>2,900</td>
<td>3,900</td>
<td>2500</td>
<td>4,300</td>
<td>5,900</td>
<td>4900</td>
<td>8,600</td>
<td>11,800</td>
</tr>
</tbody>
</table>

† For corn and soybean, soil pH 6.5 is recommended in soil association areas without calcareous subsoil and soil pH 6.0 is recommended in areas with calcareous subsoil (see text and Figure 1). Soil pH 6.9 is recommended for alfalfa and alfalfa-grass mixtures in all soil association areas. Soil pH 6.0 is recommended for other forage legumes or legume-grass mixtures and grasses in all association areas.

‡ Amounts were derived from the following calibration equations and rounded to 100 pounds:

\[
\text{Lb of CaCO}_3 \text{ to raise pH to 6.0} = [38619 - (5915 \times \text{Buffer pH})] \times \text{Depth} \times 0.167
\]

\[
\text{Lb of CaCO}_3 \text{ to raise pH to 6.5} = [49886 - (7245 \times \text{Buffer pH})] \times \text{Depth} \times 0.167
\]

\[
\text{Lb of CaCO}_3 \text{ to raise pH to 6.9} = [58776 - (8244 \times \text{Buffer pH})] \times \text{Depth} \times 0.167
\]
Calcitic vs Dolomitic Aglime

Averages of 4 Two-Year Trials Conducted in 2009-2010

Soil pH

Calcium carbonate

Calcitic aglime

Dolomitic aglime

Pagani and Mallarino, ISU

Approximately 105 days after early April lime application (when max pH reached).
Calcitic vs Dolomitic Aglime

Averages of 2 Responsive 2-Year Trials of 4 Conducted in 2009-2010

Pagani and Mallarino, ISU
Calcitic vs Dolomitic Aglime Results

- No source differences for crop yield
- The current ECCE measurement slightly over-estimated the dolomitic aglime efficiency at increasing soil pH
  - Not a major issue since didn't affect the yield response and can later check/correct soil pH
  - Dolomitic aglime adds Mg, but there is no evidence of Mg deficiency in Iowa
Pelleted Lime Research

Averages from Six Fields, 2015-2016

4.5 Months After Application

12-17 Months After Application

Calcium carbonate
Pelleted lime

Calcium carbonate
Pelleted lime

Aglime

Haq and Mallarino, ISU
Pelleted Lime Research

Averages of Responsive Fields, 2015-2016

Haq and Mallarino, ISU

**Soybean Yield (bu/acre)**

- Control
- Calcium Carbonate
- Calcitic Aglime
- Pelleted Aglime

**Corn Yield (bu/acre)**

- Control
- Calcium Carbonate
- Calcitic Aglime
- Pelleted Aglime

**ECCE Rate (ton/acre)**

- 0.0
- 2.0
- 4.0
- 6.0
- 8.0

Haq and Mallarino, ISU
Pelleted Lime Research Results

- Efficiency at increasing soil pH
  - High and similar for pure powdered calcium carbonate and pelleted lime
  - Lower for calcitic aglime mainly the first year after application
  - Current ECCE slightly over-estimate short-term aglime efficiency; OK for pelleted

- But no yield difference between sources even for a first-year crop

- Low rates, small pH increase
Test Your Soil For Acidity
C.M. Linsley and F.C. Bauer

- University of Illinois Circular 346, August, 1929
- In a 40-acre field measure pH & carbonates
  - 23 surface samples (2 inch depth)
  - 5 subsurface (12 inch depth)
  - 5 subsoil (20 inch depth)
- Completed acidity map shows where and how much limestone is needed
- Good plan to test after six years
Test Your Soil For Acidity
C.M. Linsley and F.C. Bauer

• 1929
  - Mapping native fertility patterns

• Today
  - Also mapping man's activities
    - More variable
    - Less tillage
    - Soil changes (erosion)
    - Need more samples?
    - Do as well as in 1929?
Test Your Soil For Acidity
Adapted from C.M. Linsley and F.C. Bauer

No Lime

3 Ton Limestone

2 Ton Limestone

4 Ton

J.E. Sawyer, ISU Agronomy Extension
September 1991 Soil pH

Mansfield Test Field
40 acres
16 x 16 grid
0.156 acres/sample

Soil pH
- < 5.5
- 5.5 - 6.0
- 6.0 - 6.5
- 6.5 - 7.0
- > 7.0

Data From:
T. Peck, Univ. of Illinois
J.E. Sawyer, ISU Agronomy Extension
Agricultural Limestone Application
4 Ton/acre -- October 1991

Lime Rate
- 4 ton/acre
- 0 ton/acre

Mansfield Test Field
Data From:
T. Peck, Univ. of Illinois

J.E. Sawyer, ISU Agronomy Extension
September 1992 Soil pH

Mansfield Test Field
40 acres
16 x 16 grid
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