Soil Acidity, Liming Materials and Lime RECOMMENDATIONS

HIGHLIGHTS

1 Soil pH indicates whether lime is required but not how much. Lime is needed if the target soil pH, which varies by crop, is 0.2 units higher than the actual soil pH.

2 Buffer pH indicates how much lime is required. Soils with low buffering capacity (high buffer pH) and a small difference between initial and target pH values require less lime. Conversely, soils with high buffering capacity (low buffer pH) need more lime, even for small pH adjustments.

3 Liming materials should have more than 80% calcium carbonate equivalent (CCE) and/or 50% effective neutralizing value (ENV), and the recommended lime rate should be adjusted based on these two qualities.

4 Finer lime particles are more efficient at increasing soil pH quickly due to their rapid reaction with soils. However, liming materials should contain both smaller and larger particles: the smaller particles raise the soil pH quickly, while the larger particles provide long-term control in neutralizing soil acidity.

5 The lime recommendations from the LSU AgCenter Soil Testing and Plant Analysis Lab are based on 50% effective CCE (ECCE) or ENV.

Soil Acidity and Soil pH

1. **Soil acidity** refers to the concentration of hydrogen ions (H+) in the soil, which determines the soil pH level. The pH scale ranges from 0 to 14, with a pH below 7 indicating acidity, 7 being neutral, and above 7 indicating alkalinity. Soil pH is a crucial factor in agronomic crop production because it significantly influences nutrient availability, microbial activity and overall soil health.

2. **Soil pH** is the most important soil quality component that greatly influences soil nutrient availability (see Figure 1). Most nutrients are highly available at the soil pH of 6.5. Therefore, soil pH needs to be adjusted to the target pH either by applying lime for low pH (less than 6.0) soils or by elemental sulfur for high pH (more than 7.5) soils. Increasing soil pH by liming is a more common practice than decreasing soil pH by elemental sulfur.

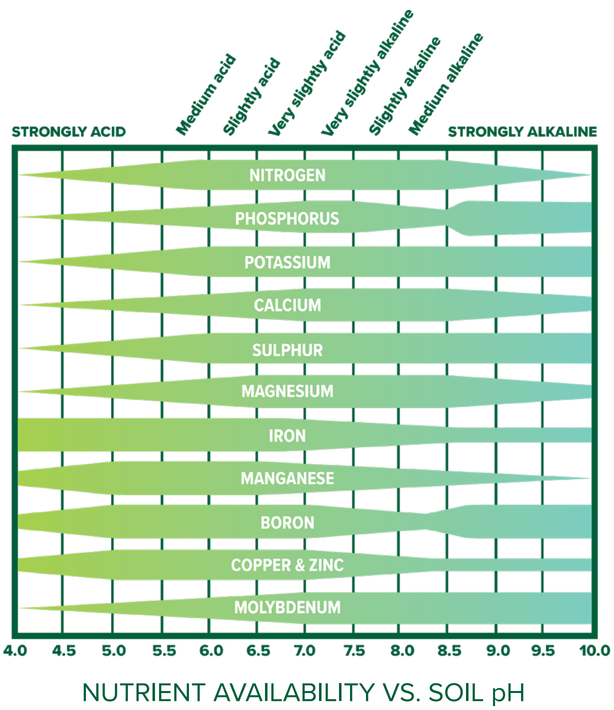

Figure 1. Soil pH and nutrient availability. Source: Reitsma et al. (2011). Chapter 2: Soil fertility. In: Alternative practices for agronomic nutrient and pest management in South Dakota. Edition: I. South Dakota State University, College of Agriculture and Biological Sciences.

Causes of Soil Acidity

1. **Weathering of parent material:** As rocks and minerals break down, they release hydrogen ions into the soil. Some parent materials (iron and aluminum minerals) are naturally more acidic than others, contributing to the overall acidity of the soil derived from them.

2. **Air pollution and acid rain:** Industrial activities release sulfur dioxide (SO_2) and nitrogen oxides (NO_x) into the atmosphere. These compounds can form sulfuric and nitric acids, which are deposited onto the soil through precipitation, contributing to acidification.

3. **High rainfall:** In areas with high rainfall, leaching removes basic cations (calcium, magnesium, potassium and sodium) from the soil, leaving acidic cations (hydrogen and aluminum) behind. This process increases soil acidity.

4. **Ammonium-based fertilizers:** Fertilizers such as ammonium sulfate, urea, and ammonium nitrate undergo nitrification when applied to the soil. This process releases hydrogen ions, which increases soil acidity.

5. **Overfertilization**: Excessive use of certain fertilizers such as ammonium (NH_4^+) containing fertilizer can lead to the accumulation of acids in the soil, further lowering the pH.

6. **Nutrient uptake by plants:** As crops grow, they absorb basic cations from the soil, which can gradually increase soil acidity.

7. **Crop harvesting:** The removal of crops from the field takes away basic nutrients from the soil, potentially leading to an acidic soil environment.

8. **Organic matter decomposition:** As organic matter decomposes, it produces organic acids (e.g., humic acid, fulvic acid) that contribute to soil acidity.

9. **Soil microbes:** Microbial activity during decomposition also releases carbon dioxide, which forms carbonic acid when it reacts with water.

10. **Saline irrigation water:** Irrigation with water containing high levels of salts can lead to soil acidification. As the water evaporates, salts are left behind, which affects soil chemical balance and increases acidity.

11. **Iron and aluminum ions hydrolysis:** In acidic soils, iron (Fe) and aluminum (Al) become more soluble and can hydrolyze, releasing hydrogen ions and further increasing soil acidity.

Importance of Managing Soil Acidity in Crop Production

1. **Nutrient availability:** Most nutrients are readily available to plants within a soil pH range of 6.0 to 7.0. Outside this range, nutrient availability decreases, potentially leading to deficiencies. Acidic soils (low pH) can result in deficiencies of essential nutrients like nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and Sulfur (S) while toxic levels of aluminum and manganese can become more available, harming plant roots and overall growth.

2. **Microbial activity:** Beneficial soil microorganisms, including those involved in nitrogen (N^2) fixation and organic matter decomposition, thrive within a neutral pH range. Acidic soils can reduce microbial activity, negatively impacting soil health and nutrient cycling.

3. **Root development and function:** Acidic soils can hinder root development and function, limiting the plant's ability to uptake water and nutrients. This can reduce crop vigor and yield potential.

4. **Fertilizer efficiency:** Proper pH management enhances the efficiency of fertilizers, ensuring that applied nutrients are available for plant uptake. This reduces the need for excessive fertilizer application, lowering input costs and minimizing environmental impact.

5. **Crop yield and quality:** Maintaining an optimal soil pH directly contributes to maximizing crop yields and quality. Proper pH management confirms that crops have access to essential nutrients throughout the growing season. Low pH negatively impacts row crop yields, as plants struggle to grow in overly acidic soils. For instance, corn performs poorly in research plots with a pH of 4.5, as observed in a long-term fertility study at Auburn University where no lime was applied since 1911 (see Figure 2).

Figure 2. Corn growth is affected by low soil pH (4.5), and no lime has been applied since 1911 for long-term fertility research at Auburn University. Photo by Md. Rasel Parvej

6. **Soil structure and health:** Appropriate pH levels promote good soil structure and aggregation, which improve water infiltration, drainage, and root penetration. This enhances overall soil health and resilience.

7. **Pest and disease management:** Certain soilborne diseases and pests are more prevalent in acidic soils. Managing soil pH can help reduce the incidence and severity of these problems.

8. **Long-term sustainability:** Regular monitoring and management of soil pH contribute to the long-term sustainability of agricultural land. It helps maintain soil fertility and productivity for future crop cycles.

Effective soil acidity management is fundamental to achieving optimal nutrient availability, enhancing soil health, improving crop yield and quality, and promoting sustainable agricultural practices. Regular soil testing and appropriate amendments, such as lime application, are essential components of this management strategy.

Buffer pH

Buffer pH is a measure of the soil capacity to resist changes in pH when acids or bases are added. This concept is crucial in soil science, especially for managing soil acidity and making lime recommendations. Here is a detailed look at buffer pH and its importance:

1. **Buffering capacity:** Buffer pH indicates the buffering capacity of the soil, which is the ability of soil to maintain a stable pH despite the addition of acidic or basic substances. Soils with a high buffering capacity (low buffer pH) can neutralize added acids or bases more effectively than soils with a low buffering capacity (high buffer pH). When conducting soil tests, a buffer pH test is often included alongside the regular pH test. This involves adding a buffering solution to the soil and measuring the pH change, which indicates soil buffering capacity.

2. **Soil components contributing to buffering:**
   - **Clay minerals:** Soils with high clay content generally have a higher buffering capacity due to the large surface area of clay particles, which can hold onto and exchange cations.
   - **Organic matter:** Organic matter can also contribute to buffering capacity by providing sites for cation exchange and by releasing organic acids during decomposition.
   - **Carbonates:** The presence of calcium carbonate (lime) and other carbonates can significantly increase the buffering capacity by neutralizing acids.

3. **Lime requirement determination:** Buffer pH is used to calculate the amount of lime required to increase the soil pH to a targeted level. This is crucial because simply knowing the soil pH does not provide enough information about how much lime is required to neutralize acidity. Based on the buffer pH, agronomists can provide precise lime recommendations. For example, most land-grant universities use buffer pH to tailor lime application rates to the specific needs of different soils.

   The required rate of lime depends on the initial soil pH, target pH and soil buffering capacity (buffer pH). Soils with low buffering capacity (high buffer pH) and a small difference between initial and target pH values require less lime. Conversely, soils with high buffering capacity (low buffer pH) need more lime, even for small pH adjustments. Clay (fine-textured) soils, having higher buffering capacity, require more lime to increase soil pH compared to silt loam (coarse-textured) soils. The LSU AgCenter Soil Testing and Plant Analysis Lab does not determine lime requirements based on buffer pH but provides an estimate of pH change with the addition of up to 3 tons of lime per acre, leaving producers to decide on the exact amount based on a cost-benefit analysis.

4. **Target soil pH:** Set the target soil pH based on the crop to be grown. For instance, soybean is more sensitive to low soil pH than corn and cotton. The target soil pH should be 6.3 for soybean and 6.0 for corn and cotton. Lime is necessary if the target pH is 0.2 units higher than the actual soil pH. For example, a producer tests his clay field for soybean production and finds a pH of 5.5, indicating acidity. However, the buffer pH test shows a high buffering capacity (buffer pH 6.0), suggesting that a large quantity of lime will be needed to raise the pH to the optimal level of 6.3.

Understanding buffering capacity is essential for making informed decisions about soil amendments and management practices. It ensures the correct amount of lime is applied to achieve optimal soil pH for crop production, avoiding the economic inefficiency and potential harm caused by over-application or under-application. Overall, buffer pH is a crucial tool for managing soil acidity, facilitating precise lime recommendations, maintaining soil health, and optimizing crop production. Regular soil testing, including buffer pH, should be a key component of any agronomic management plan to ensure sustainable and productive farming practices.

Lime Quality

1. **Quality of liming materials:** The quality of liming materials is crucial for raising soil pH. Two key qualities determine this: purity and particle size. The purity of a liming material is measured against pure calcium carbonate ($CaCO_3$, calcitic limestone), which is rated as 100% (since the molecular weight of pure calcium carbonate is 100 g) and is referred to as calcium carbonate equivalent (CCE).

2. **Particle size:** The particle size, also known as the fineness factor of the liming material, is expressed as the percentage of the material that passes through various-sized screens. The greater the percentage of material passing through a finer screen (i.e., smaller holes), the higher the fineness factor. Finer particles are more effective in neutralizing soil acidity and raising soil pH because they react more quickly with the soil due to their larger surface area. However, a good distribution of particle sizes, including both smaller and larger particles, is necessary. Smaller particles quickly raise soil pH, while larger particles provide long-term control of soil acidity. Current Louisiana recommendations for ground lime specify that 90% of the material should pass through a 10-mesh sieve, 50% through a 60-mesh sieve and 20% through a 100-mesh sieve.

3. **Effective CCE (ECCE) or effective neutralizing value (ENV):** Both the purity (CCE) and particle size (fineness factor) of the liming material are combined to express the ECCE or ENV. The higher the ECCE or ENV, the more efficient the liming material is at increasing soil pH.

Liming Materials

The choice of liming material depends on its neutralizing value, cost, availability, and ease of application. Common types of liming materials include:

1. **Calcitic lime (calcium carbonate - $CaCO_3$)**
   - CCE of commercially available product: 90%-100%.
   - Pure calcium carbonate, often referred to as agricultural lime.
   - Effective in neutralizing soil acidity and adding calcium.
   - Most commonly used lime products in agronomic crop production systems. We are conducting lime research using agricultural lime with a CCE of 87% (see Figure 3).

2. **Dolomitic lime (calcium magnesium carbonate - $CaMg(CO_3)_2$)**
   - CCE of commercially available product: 95%-108%.
   - Contains both calcium and magnesium carbonates.
   - Beneficial for soils deficient in magnesium.

Figure 3. Agricultural lime, left, and ongoing research with agricultural lime, right, at the LSU AgCenter Macon Ridge Research Station in Winnsboro, Louisiana. Photos by Md. Rasel Parvej

3. **Quicklime (calcium oxide - CaO)**
   - CCE of commercially available product: 150%-175%.
   - Produced by heating limestone to drive off carbon dioxide (CO_2).
   - Very reactive and fast-acting but requires careful handling due to its caustic nature.

4. **Hydrated lime (calcium hydroxide - $Ca(OH)_2$)**
   - CCE of commercially available product: 120%-135%.
   - Produced by adding water to quicklime.
   - Highly reactive and fast-acting, useful for rapid pH adjustment.

5. **Marl**
   - CCE of commercially available product: 70%-90%.
   - A natural mixture of calcium carbonate and clay.
   - Less concentrated than calcitic or dolomitic lime but still effective.

6. **Burnt lime**
   - CCE of commercially available product: 150%-175%.
   - Another term for quicklime, emphasizing its production through heating.

7. **Liquid lime**
   - CCE of commercially available product: Varies (typically lower than dry limes due to dilution).
   - Lime suspended in water for easier application.
   - Provides more uniform coverage but may be more expensive.

8. **By-product limes**
   - CCE of commercially available product: Varies (depends on the specific by-product).
   - Includes materials like wood ash, sugar beet lime, and industrial by-products.
   - Their effectiveness varies, so they should be tested for neutralizing value.

Pelletized Lime (Is it better than ag lime?)

Pelletized lime is a type of agricultural lime that has been processed into small, uniform pellets for easier handling and application. Pelletized lime is made from finely ground agricultural (ag) lime. The fineness typically involves particles that are less than 100 mesh. The lime can be either dolomitic (containing calcium magnesium carbonate) or calcitic (containing calcium carbonate), depending on the nature of the original limestone. During the pelletizing process, the fine lime particles are bonded together with a binding agent, commonly lignosulfonates. Pelletized lime generally contains about 9% lignosulfonates. Due to its higher cost, pelletized lime has been primarily used in horticultural crops and golf courses where its ease of application and aesthetic value are significant advantages. Although historically less common in large-scale production agriculture due to its cost, pelletized lime is becoming more widely used in this sector.

Advantages

- The pellet form makes it easier to spread uniformly using standard fertilizer equipment, reducing dust and making the application process cleaner and more efficient.
- Pelletized lime is easier to store and handle compared to bulk ag lime, leading to less wastage and more precise application.

Disadvantages

- The price of pelletized lime is significantly higher per ton compared to bulk agricultural lime, affecting its economic feasibility for large-scale agricultural use.
- There are ongoing discussions regarding the speed at which pelletized lime reacts with soil compared to standard agricultural lime. Although pelletized lime may react relatively quickly upon breakdown, it often does not react faster than finely ground ag lime in the field. Its rate of pH change depends on how quickly the pellets break down and disperse. This slower-than-expected reaction is likely due to two factors: 1) the lignosulfonate binding agent, which must break down through solubilization or microbial action before the lime is released to neutralize soil acidity, and 2) the distribution pattern, as pelletized lime tends to form small, concentrated zones rather than being evenly distributed.
- When pelletized lime is spread, it results in small, concentrated zones (spots) of lime after the binder dissolves. In contrast, ag lime is spread as a fine dust, leading to better distribution across the soil and greater contact with the soil particles. This bulk spreading method allows ag lime to contact a larger amount of soil.
- Recommended application rates for pelletized lime may differ from those for standard ag lime. Producers tend to use lower rates due to the higher CCE and cost of pelletized lime.
- When applied at low rates, pelletized lime provides little to no residual liming effect, meaning it may not sustain soil pH levels as effectively over time

Pelletized lime offers practical advantages in terms of ease of application and handling, making it ideal for horticulture and specialty markets. Its use in production agriculture is increasing, but factors such as cost, reaction speed and application rates must be carefully considered for effective use. In production agriculture, pelletized lime should be broken down by rainfall after broadcasting before being incorporated into the soil with tillage. If incorporated immediately after broadcasting, it will take longer to break down under the soil.

Neutral Salts (are not liming materials)

Neutral salts are not liming materials. They are chemical compounds formed from the reaction of a strong acid with a strong base, resulting in a salt that does not affect the pH of the solution significantly. These salts are called neutral because they do not significantly change the hydrogen ion concentration (pH) when dissolved in water. Examples are sodium chloride (NaCl), potassium chloride (KCl), potassium nitrate (KNO_3), calcium sulfate ($CaSO_4$), ammonium chloride (NH_4Cl), etc.

Mechanism of Agricultural Lime in Neutralizing Soil Acidity

Calcium carbonate ($CaCO_3$), commonly referred to as ag lime, is mainly used to neutralize soil acidity and improve soil health for better crop production. Here is how ag lime works to neutralize soil acidity:

1. **Dissolution of lime in soil water:** When ag lime is applied to the soil, it dissolves in the soil water and releases calcium (Ca^{2+}) ions into the soil solution.
2. **Neutralization reaction:** The released calcium ions react with hydrogen ions (H^+) present in the acidic soil. This reaction forms water (H_2O) and carbon dioxide (CO_2), effectively neutralizing the acidity. The primary chemical reactions are as follows:
   - For calcitic lime (calcium carbonate):
     $CaCO_3 + 2H^+ \text{ (soil)} \rightarrow Ca^{2+} + CO_2 + H_2O$

3. **Exchange with soil acidity:** The calcium ions from the dissolved lime displace the acidic hydrogen (H^+) and aluminum (Al^{3+}) ions adsorbed on the soil CEC/colloids (clay and organic matter). This process, called cation exchange, further reduces soil acidity:
   - Exchange of hydrogen ions:
     $Ca^{2+} + 2H^+ \text{ (soil)} \rightarrow 2H^+ + Ca^{2+} \text{ (soil)}$
   - Exchange of aluminum ions:
     $3Ca^{2+} + 2Al^{3+} \text{ (soil)} \rightarrow 2Al^{3+} + 3Ca^{2+} \text{ (soil)}$

4. **Formation of carbon dioxide:** The hydrogen ions neutralized by the carbonate ions (CO_3^{2-}) from the lime form water or aluminum hydroxide and carbon dioxide. The carbon dioxide is released into the atmosphere or absorbed by the soil and aluminum hydroxide precipitates:
   - $CO_3^{2-} + 2H^+ \rightarrow CO_2 + H_2O$
   - $3CO_3^{2-} + 2Al^{3+} + 3H_2O \rightarrow 2Al(OH)_3 + 3CO_2$

The neutralization of acidity by lime is a gradual process. Over time, the added calcium ions continue to replace the acidic cations on the soil colloids, leading to a sustained increase in soil pH. Regular applications (every year/every other year) may be needed depending on soil buffering capacity and acidification rate from ongoing farming practices.

Lime Application Rate

The lime rate recommended by soil testing labs is based on pure calcitic limestone with 100% CCE. Therefore, the actual application rate should be adjusted according to the CCE of the liming material. For example, if the CCE of the liming material is 80% and the recommendation is 2 tons per acre, then 2.5 tons (2 tons/0.80) per acre should be applied. Similarly, if recommendations are based on ENV, adjustments must be made according to the ENV or ECCE of the liming material. For instance, if the ENV of the liming material is 60% but the recommended rate is based on a standard calcium carbonate with 90% ENV, then 1.5 tons (0.9/0.6) per acre should be applied for every ton of lime recommended. Note that lime recommendations from the LSU AgCenter Soil Testing and Plant Analysis Lab are based on 50% ECCE or ENV.

Applying the right liming material in the correct amount is crucial for achieving the desired soil pH, enhancing nutrient availability, and promoting healthy crop growth. Regular soil testing helps determine the specific lime requirements and ensures sustainable soil management.

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