TECHNICAL NOTE 3.
SOIL ACIDITY AND LIMING

3.0 Background

Farmers sometimes refer to acid soil as "sour" and alkaline soil as "sweet". The terms *sweet* and *sour* were likely inherited by the Greeks and Romans from antiquity, who observed differences in the taste of water percolated through different soils. Columella, a Spaniard living in Rome about 45 A.D., noted that "sour" soil was less productive, whereas "sweetening" the soil with lime increased growth. In the United States, Virginia farmer-scientist Edmund Ruffin was the first to use lime during the period 1825-1845. Today we know much more about sweet and sour soils than our ancestors did. Yet the origins of soil acidity (and alkalinity) and the influence of lime are still a bit mysterious to the average person. In this technical note, we'll try to clear up some of the mystery surrounding soil acidity.

In general, acidity is associated with soils that have undergone a long period of weathering typical of the earth's humid regions, whereas alkalinity occurs mainly in drier regions. Soils of humid regions have developed under conditions in which rainfall exceeds the amount of water used by crops plus losses from surface evaporation (i.e., *evapotranspiration*). Soils formed under these conditions are said to be *leached* and show a gradual depletion of plant-essential cations (e.g., Ca^{2+}, Mg^{2+}, K^{+}) and an increase in hydrogen (H^{+}) and soluble aluminum (Al^{3+}). Acidity depends on the concentration of hydrogen ions in a solution and is quantified by the soil's pH.[1] But where does the acidity come from? How does acidity affect plants? How is acidity managed? Read on…

3.1 Origin of Soil Acidity

There are numerous sources of soil acidity, both internal (originating from *within* the soil) and external (from sources *outside* of the soil).

Internal sources:

- Root and microbial respiration produce CO_2, which dissolves to produce carbonic acid in the soil solution. Carbonic acid is a weak acid that produces H+ when the soil pH is above 5 and can be a major source of soil acidity.
- H^{+} is released during the decomposition of soil organic matter as a result of mineralization and nitrification.
- Organic acids are released from vegetation, soil organic matter, and plant roots.
- Roots release H^{+} or OH^{-} to maintain electrical neutrality at their surfaces during the uptake of nutrient ions. As such, they can function as either acids or bases.
- Soil-forming minerals release H^{+} during weathering via contact with acidic rain and soil water.

External sources:

- Rainwater. When atmospheric moisture condenses to form rain, it is pure water with a neutral pH of 7. But as soon as pure water comes in contact with atmospheric CO_2 (about 0.04% as of 2025), a dilute carbonic acid solution is formed with a pH of 5.7:

$$\underset{\text{water}}{H_2O} + \underset{\text{carbon dioxide}}{CO_2} \rightleftharpoons \underset{\text{carbonic acid}}{H_2CO_3}$$

  Rainwater with a pH different from 5.7 must contain another acid or base. Nitric and sulfuric acid (or ammonia and oxides of N and S) from industrial sources may be dissolved in the atmosphere and cause rainwater to have a pH less than 5.7. These are washed into the soil by rain and produce acidity.

- Fertilizers (including farmyard manure) that contain ammonium (NH_4^{+}) increase acidity due to the nitrification of ammonium salts by soil bacteria:

$$\underset{\text{ammonium}}{2NH_4^+} + \underset{\text{oxygen}}{4O_2} \rightarrow \underset{\text{nitrate}}{2NO_3^-} + \underset{\text{acid}}{4H^+} + \underset{\text{water}}{2H_2O}$$

Not all of the acidity entering or produced in the soil remains in the soil solution. This is due to differences in soil properties and the climate. Consequently, we can speak figuratively of acidity "sinks" that tend to buffer the effect of acids introduced to the soil. Important acidity sinks include:

- Parent materials that are basic (limestone, marl) react with water to give a pH of 7 or higher.
- Ion exchange reactions on clays, and reaction with iron and aluminum oxides, and organic matter, remove H^{+} from solution in exchange for basic cations.
- Leaching removes H^{+} from the soil when it combines with OH^{-} to form water.

In effect, the presence of acidity sinks in the soil results in a smaller decrease in pH in the soil solution than if the same amount of acid were introduced to water. This is known as soil *buffering capacity* and varies depending on soil texture, organic matter, and mineral characteristics.

[1] Readers who are unfamiliar with the fundamental chemical property of pH are strongly encouraged to read Technical Note 4 Understanding pH: Theory, Measurement, Application as background (link).

3.2 Acid Soil Infertility

Poor plant growth on acid soils is usually associated with low soil pH. This is called *acid soil infertility*. Acid soil infertility results from a complex of interacting factors, principally:

- Removal of exchangeable basic cations (Ca^{2+}, Mg^{2+}, K^{+}) by leaching in drainage water and by crops.
- Increase in soluble aluminum (Al^{3+}) at pH < 5.5.
- Phosphorus fixation by aluminum and iron, resulting in phosphorus deficiency.
- Micronutrient deficiency (molybdenum) and toxicity (manganese).
- Reduced root activity and nutrient uptake.

In acid mineral soils, poor plant growth is primarily due to elevated Al^{3+} concentrations in solution. Aluminum (chemical symbol: Al) is a common constituent in mineral soils because many of the earth's rocks are rich in this element. Aluminum toxicity is the main plant growth-inhibiting factor in acidic soil, but not all forms of soil aluminum are harmful to plants. The soluble, or exchangeable, Al^{3+} ion generated in strongly acidic soil is the toxic species. As the concentration of Al^{3+} in the soil solution increases, root growth and function decrease (Figure 1). Root injury is observed at pH 5 and lower. A visual inspection of the root system often reveals stubby, truncated lateral roots that are brown or dull gray. At low pH and low calcium levels, root membrane permeability is impaired. This makes it difficult for plants to assimilate minerals, such as nitrogen, that may be present in plant-available forms.

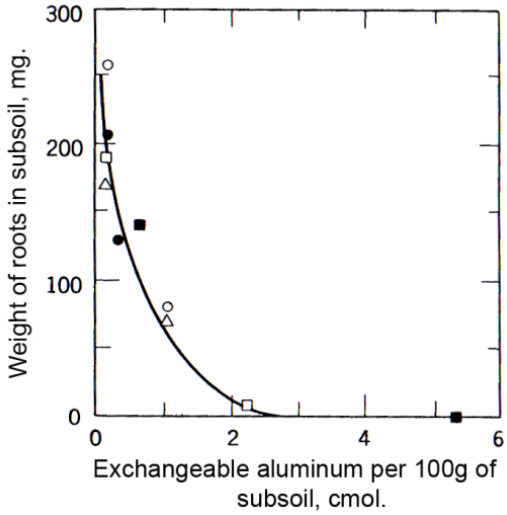


Figure 1 Relationship of root weight and exchangeable aluminum in different subsoils. Legend for subsoils:
• Norfolk; ○ Goldsboro; Δ Lynchburg; □ Rains;
■ Portsmouth. (*source: Ragland and Coleman, 1959*)

Plants suffering from acid soil infertility often show symptoms of stunting, yellowing, and in extreme cases, acute toxicity. The subsoil in humid zones is often acidic despite repeated liming of the surface soil. Much of the poor root development (and drought susceptibility) seen in acid subsoil is due to aluminum toxicity, which limits rooting depth and branching.

Aluminum is strongly complexed by organic matter. Consequently, soils high in organic matter have less Al^{3+} in solution because aluminum is bound tightly within the organic fraction. Increasing soil organic matter content, either through the addition of farmyard manure or crop and cover crop residues, can reduce soluble Al^{3+} levels and improve plant growth (and confer other benefits).

Low soil pH also affects the activity of many important soil microorganisms. Nitrification of NH_4^{+} (Figure 2) and nodule formation by *Rhizobium* bacteria on the roots of legumes (Table 1) are reduced. In general, bacteria predominate in near-neutral soils, whereas fungi predominate in acid soils. This shift in the microbiological community can have important effects on soil productivity.

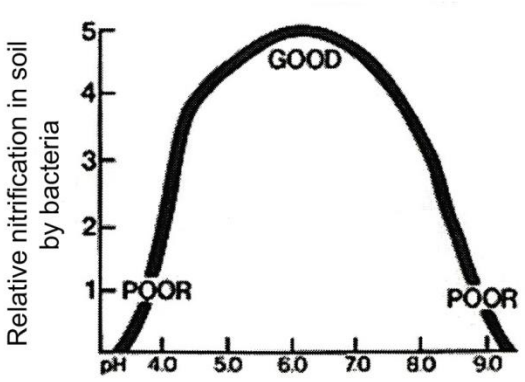


Figure 2 Relationship of soil pH to nitrification.

Table 1.

pH	Nodule Number (soybeans)
4.7	21
5.0	64
6.0	77

pH affects the availability of essential plant nutrients (Figure 3). Phosphorus (P) in particular has a narrow pH range over which it occurs in plant-available form. Neutralization of exchangeable Al^{3+} by liming increases plant response to P fertilizer additions. Much lower rates of fertilizer P are needed for optimum growth when exchangeable Al^{3+} is neutralized. The availability of molybdenum (Mo) is very low in acid soil due to fixation by hydrous oxides of Al and Fe. Molybdenum is an essential component of the nitrogenase enzyme controlling the fixation of atmospheric N_2 to NH_3 by *Rhizobium* bacteria living symbiotically on the roots of legumes. Legumes growing in acid soil often show symptoms of N deficiency resulting from reduced N-fixing ability caused by a lack of available Mo.

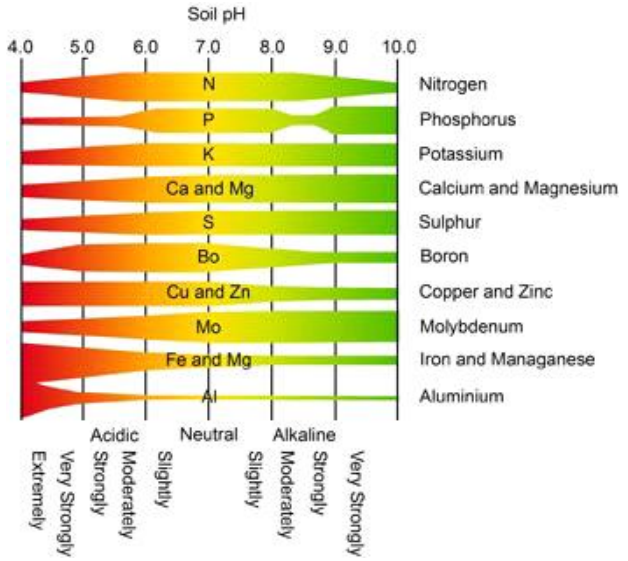


Figure 3 Effect of pH on nutrient availability.
Source: *www.terragis.bees.unsw.edu.au/TerraGIS_soil*

3.3 Soil pH and Liming

To neutralize an acid soil, agricultural lime (aglime) is normally used. A liming material must: (1) contain calcium or magnesium, and (2) contain sufficient carbonates to raise pH. Lime usually consists of finely ground carbonates of calcium and magnesium, although the term also includes oxides and hydroxides of calcium. Some liming materials include:

- ***Dolomite*** Pure dolomite is a mineral composed of 40–45% magnesium carbonate ($MgCO_3$) and 54–58 % calcium carbonate ($CaCO_3$). *Dolomitic limestone* is a material containing less $MgCO_3$ and $CaCO_3$ than pure dolomite. State law controls the purity of material sold as dolomitic lime.

- ***Calcite*** Pure calcite is a mineral occurring in nature, composed of 100% $CaCO_3$. Calcite occurs in many materials, e.g., calcitic limestone, marble, chalk, marl, seashells, and eggshells. Because the mineral calcite is pure $CaCO_3$, it is the standard by which the acid-neutralizing ability of *all other liming materials* is measured.

- ***Quicklime*** This is a form of burned limestone, calcium oxide (CaO). Quicklime is formed by heating $CaCO_3$ in a kiln to drive off CO_2. Quicklime is a caustic powder and is difficult to handle. Quicklime is rapid-acting and can neutralize soil acidity within days. It must be thoroughly mixed with soil to be effective. Quicklime reacts with water to form hydrated lime, consuming water at a rate of 30% by weight. It is no longer used directly for land application in agriculture but is employed in construction earthwork to desiccate soil and reduce the plasticity of clays (stabilization). It is also widely used to stabilize fertilizer biosolids and manure piles, reducing odor and insect problems.

- ***Hydrated (slaked) Lime*** Hydrated lime is formed by adding water or steam to quicklime. Calcium oxide reacts with water to form calcium hydroxide: CaO + H2O • $Ca(OH)_2$. Hydrated lime is also caustic and fast acting. It is used to make cement and mortar; hence the common name 'builder's lime'.

- ***Blast Furnace Slag*** This is a by-product of the manufacture of pig iron from iron ore and limestone. Limestone is used to remove impurities from molten iron ore. During burning, Silica (SiO_2) from the ore unites with calcium from the limestone to form calcium silicate ($CaSiO_3$ and $CaSiO_4$). Carbon dioxide is driven off by heating, as in the production of quicklime. *Basic slag* is formed in a similar manner from iron ore that contains phosphorus (an impurity). Basic slag is a source of both calcium and phosphorus, but the P content is variable depending on the amount of P in the iron ore.

- ***Marl*** ($CaCO_3$) is a natural substance that is sometimes used as a liming material. It is a loosely consolidated earthy material composed mainly of shell fragments and calcium carbonate precipitated in freshwater ponds from drainage waters high in lime. Marl often contains considerable impurities, including sand, silt, and clay. *Chalk* is a soft, porous limestone found in marine deposits and is chemically similar to marl.

- ***Wood Ash*** Whenever wood is burned, oxides and hydroxides of calcium, magnesium, potassium, etc., are formed. These alkaline compounds are effective at neutralizing soil acidity. Wood ash is caustic and should be thoroughly mixed into soil, and should not come into direct contact with plant roots. *Fly ash* is a by-product from coal-burning plants that also has acid-neutralizing value. The burned residues of herbaceous plants (greenwaste, hardwood leaves, straw) also contain oxide compounds similar in composition to wood ash and have a liming value.

- ***Manure*** Composted manures may contain large quantities of carbonates and thus have a liming value. The actual carbonate content varies among animals and diets. As such, the liming value of manure is unpredictable. Poultry manure, in particular, is rich in lime, which is added to the feed. Most of this passes through the animal. Overuse of poultry manure as a fertilizer poses a risk of raising soil pH excessively.

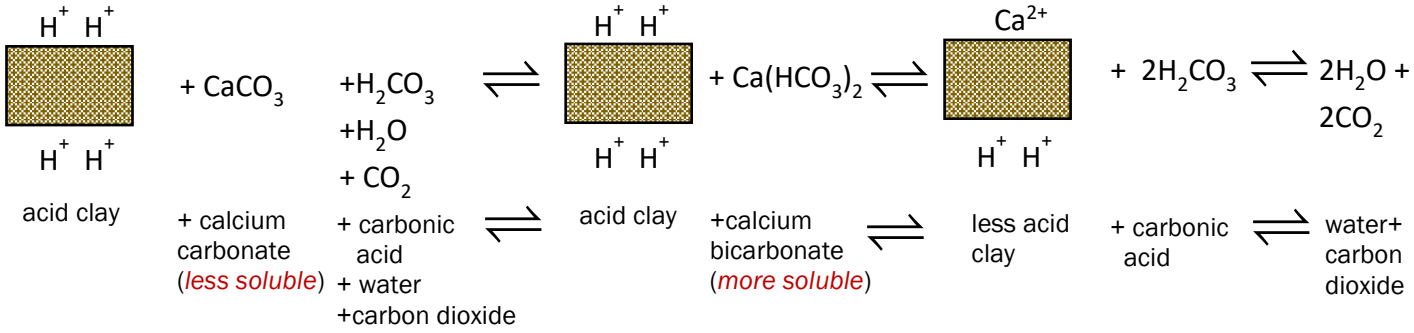
Fluid or liquid lime is prepared by mixing finely ground calcium carbonate with water and a suspending agent (attapulgite clay) so the material can be spread with liquid fertilizer application equipment. The main benefits include: (1) more rapid reaction of lime in the soil due to the finer particle size, and (2) more precise application. The drawbacks include: (1) greater cost, (2) the amount of lime that can be suspended in a liquid (about 1,000 lbs per ton of liquid) limits the application rate, and (3) more finely divided particles have less residual effect on pH, making more frequent applications necessary.

Pelletized lime (granular) is prepared by adding a binding agent to finely ground aglime to obtain a granular material suitable for application with dry granular fertilizer equipment. Pelletized lime is less prone to off-target wind drift and is easier to spread, but the pelletizing process adds to the cost. Pelletized lime comes in contact with fewer soil

particles as compared to finely ground lime. As a result, soil pH changes are slower with the pellets. Pelletized lime is not an economical choice for most growers, but is often used in landscaping and home gardens. Pelletized lime has the same neutralizing value as aglime.

3.4 How Does Lime Work?

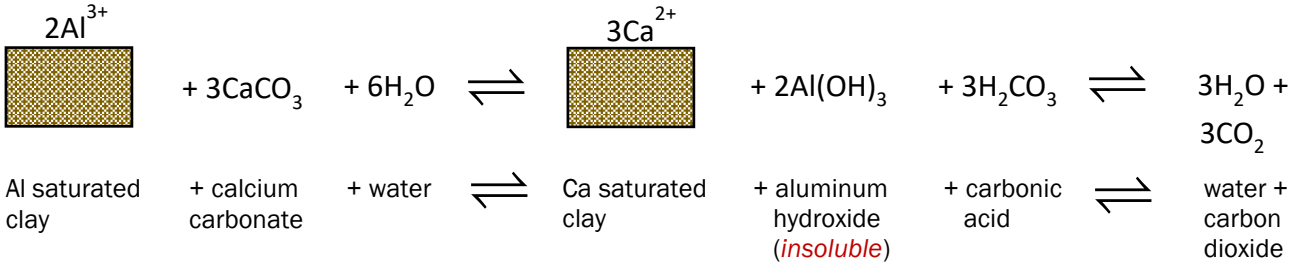
When lime is introduced to acid soil, the following reactions take place:



As $CaCO_3$ is added to the soil to increase soil pH, it reacts with carbonic acid (H_2CO_3, a weak acid formed by water and carbon dioxide) to form calcium bicarbonate, a more soluble (and leachable) intermediate. Calcium bicarbonate ionizes, allowing calcium ions to replace hydrogen ions at the exchange sites of clay particles. Since calcium is a divalent ion, it replaces two hydrogen ions. The displaced hydrogen ions react with bicarbonate ions, forming carbonic acid; however, because more carbonic acid is present than is permitted by the CO_2 concentration in the soil air, carbonic acid decomposes to water and CO_2. The overall result is increased base saturation, increased pH, and decreased hydrogen ion concentration. Note that the carbonates and oxides in lime increase pH by neutralizing hydrogen ions. Calcium and magnesium in lime *increase the base saturation*.

Earlier, we noted that as soil pH decreases, the concentration of toxic soluble Al^{3+} increases. Aluminum is a cation similar to calcium, magnesium, and potassium in that it participates in cation exchange reactions on clay surfaces. In fact, Al^{3+} is preferentially adsorbed onto clays due to its higher valence (+3) relative to calcium and magnesium.

In acid soils, clays are often saturated with a mixture of hydrogen and aluminum. However, aluminum differs from other cations in that it reacts with water in a process called *hydrolysis* (literally, splitting of water). Water naturally dissociates to form H^+ and OH^- ions. Aluminum combines with OH- ions to form the insoluble aluminum hydroxide, $Al(OH)_3$, leaving H^+ ions in solution. In acid soils, aluminum is without OH^- ions, while H^+ ions are numerous. The balance is therefore shifted toward the formation of soluble Al^{3+}. When lime is added to the soil, some H^+ ions are neutralized. This causes aluminum to hydrolyze water, releasing more H^+ ions in solution, which tends to maintain soil acidity. Calcium in lime can replace exchangeable aluminum on clay particles when a sufficient amount is added. This aluminum dissolves in water, reacting to produce additional H^+ ions. As more lime is added, the reaction continues until all the exchangeable aluminum is consumed. The above process is reversed by the increasing concentration of H^+ ions during soil acidification. The behavior of aluminum in the soil can be very complex, but its reaction with lime can be simplified as:



To summarize, the beneficial effects of liming soil are:

- Neutralization of exchangeable Al^{3+}
- Increased Ca and Mg base saturation
- Increased P and Mo availability
- Stimulates microbiological activity in the soil
- Better growth from many legumes that rely on pH-sensitive symbiotic bacteria for N-fixation
- Improved physical structure of the soil by clumping together, or *flocculation,* of clays into more stable aggregates

3.5 Are All Aglime Materials Equal?

The short answer is no. The two principal factors influencing lime quality are: (1) its acid-neutralizing capacity, and (2) the fineness to which it is ground. The acid-neutralizing capacity is usually measured as the *calcium carbonate equivalent* (CCE).

The CCE is defined as the acid-neutralizing capacity of a liming material expressed as a percent by mass of pure $CaCO_3$.

In other words, pure calcite has a CCE of 100%. **All liming materials are referenced to pure $CaCO_3$.** Because CCE is expressed in terms of mass, liming materials with a molecular mass *less than* pure $CaCO_3$ have CCEs greater than 100 percent, and liming materials with a molecular mass greater than pure $CaCO_3$ have CCEs *less than* 100 percent. To determine the CCE of a liming material, we simply divide the molecular mass of the material by the molecular mass of the standard, $CaCO_3$:

$$\%\text{CCE} = \frac{\text{grams of pure } CaCO_3 \text{ equal to 100 grams of } (x) \text{ lime material}}{\text{100 grams of pure } CaCO_3} \times 100$$

To compare burned lime (CaO), we must first determine its molecular mass. The molar mass of calcium is 40, and oxygen is 16. Combined, they equal 56 g/mol. The molecular mass of pure $CaCO_3$ is: calcium (40) + carbon (12) + oxygen (3 x 16= 48) = 100 g/mole. Dividing 100 by 56 yields 1.79 (rounded). Therefore, the answer is given by:

$$\%\text{CCE} = \frac{179 \text{ g } CaCO_3 \text{ is equal to } 100 \text{ g CaO}}{100 \text{ g of pure } CaCO_3} \times 100$$

$$= 179\% \text{ CCE for CaO.}$$

A liming material having a CCE of 179% means only 0.56 ton (100/179) is required to have the equivalent neutralizing value of one ton of pure $CaCO_3$. North Carolina has no minimum CCE requirement for aglime materials, but the label must indicate the amount of material required to achieve 90 percent CCE. Also, in North Carolina, 90 percent CCE is the basis for lime recommendations.

The amount of impurities in a lime material will affect its CCE. For example, pure CaO has a CCE of 179%, as noted above. However, impurities in CaO can cause the CCE to vary between 150% and 179%. The only way to determine CCE exactly is to react a carefully weighed sample of the liming material with a known volume of acid (e.g., HCl) under laboratory conditions and titrate the residual acidity with a standardized base (e.g., NaOH). Table 2 shows the CCEs of some liming materials.

The other major factor influencing lime quality is the fineness of grind. As particle size decreases, a liming material dissolves more rapidly and changes pH over a shorter period. Particle size is related to the efficiency of a liming material, i.e., how quickly it will effect a change in soil pH over a given time period. To characterize the particle-size distribution of lime, a representative sample of the material is sieved through sieves of different mesh sizes. An 8-mesh sieve has 8 openings per linear inch in both directions, corresponding to one-eighth inch per opening. Lime particles retained on an 8-mesh sieve are larger than one-eighth inch in diameter.

Table 2.

Liming material	Common name	Formula	CCE [a]
Calcium carbonate	Calcite, aragonite	$CaCO_3$	100
Calcitic limestone	High cal	$CaCO_3$ [b]	8-100 [b]
Calcium oxide		CaO	179
Burnt lime	Builder's lime	CaO [b]	150-179 [b]
Calcium hydroxide		$Ca(OH)_2$	136
Hydrated lime	Slaked lime	$Ca(OH)_2$	120-136
Dolomite		$CaCO_3$ $MgCO_3$	109
Dolomitic limestone	Dolomite, aglime	$CaCO_3$ $MgCO_3$ [b]	to 108 [b]
Calcined dolomite	Burnt dolomite	CaO MgO[b]	to 185 [b]
Hydrated dolomite	Hydrated dolomite	$Ca(OH)_2$ $Mg(OH)_2$	to 166 [b]
Calcium silicate		$CaSiO_3$	86
Basic slag [c]	Thomas slag	$CaSiO_3$	to 86 [b]
Blast furnace slag [c]		$CaSiO_3$	to 86 [b]
Open hearth slag [c]		$CaSiO_3$	to 86 [b]
Ashes, coal		variable	0-40
Ashes, wood [d]		variable	to 80
Marl		variable	70-90
Portland cement [e]		variable	to 100
Sugar beet lime [f]		variable	80-90
Shells	Ground oyster, egg	$CaCO_3$ [b]	75-90 [b]

[a] Relative values with $CaCO_3$ = 100.

[b] May have various impurities, modifying their composition and CCE.

[c] Slags contain variable amounts of Ca, Mg, and P. Basic slag contains 27-42 percent Ca, 1-5 percent Mg, and 5-10 per cent P; blast furnace slag contains 26-32 percent Ca, 2-7 percent Mg, and < 1 percent P; open hearth contains about 16 percent Ca, 5 percent Mg, and 1 percent P. Slags may also contain micronutrients.

[d] Unleached wood ashes can contain 1 percent P, 4-21 percent K; leached wood ashes about 0.5 percent K, and 1 percent K_20. Both contain variable amounts of micronutrients.

[e] Can contain varying amounts of K.

[f] Contains 0.05-0.6 percent P, with an average content of 0.38 percent. (*source: Wolf, B. 1999.*)

Table 3 gives the efficiency factors for various limestone particle sizes. The coarser materials, larger than 8-mesh diameter (> 8-mesh), are very slow to react; only 5 percent of materials > 8-mesh will react one year after application. On the other hand, 100 percent of the material passing through a 60-mesh screen reacts within the same time period. Material passing 8-mesh but retained by 20-mesh, and the 20- to 60-mesh fraction is intermediate in reactivity. Particle size is such an important aspect of lime quality that laws governing particle size specifications for aglime have been adopted by most states, including North Carolina.

Table 3. FINENESS EFFICIENCY FACTOR

Particle Size	% Reacted: One year after application	% Reacted: Four years after application
> 8-mesh	5	15
8- to 20-mesh	20	45
20-to 60-mesh	50	100
Passing 60 mesh	100	100

The best way to evaluate the effectiveness of a liming material is to first determine the CCE, then use sieve analysis (which quantifies fineness) to calculate the effective neutralizing value (ENV), accounting for both chemical and physical quality parameters. Following is an example of how this is done using a four-sieve analysis:

Problem: The results of a soil test indicated a need for 2,000 lb/acre of lime. The recommendation is based on a minimum CCE of 90% and a fineness factor of 100. The grower uses a locally available lime product with 85% CCE and the following sieve analysis: 0–8 mesh, 10%; 8–20 mesh, 21%; 20–60 mesh, 25%; and > 60 mesh, 55%. How much lime should the grower apply?

ENV = CCE x Fineness Factor

The fineness factor is calculated:

0.10	x	5	=	0.5
0.21	x	20	=	4.2
0.25	x	50	=	12.5
0.55	x	100	=	55.0
Fineness factor			=	**72.2**

ENV = CCE (0.85) x Fineness Factor (72) = 62

The relative value of the local product is found by dividing the ENV of the liming material on which the recommendation is based by the ENV of the local product: 100/62 = 1.6. This is the correction factor used to solve the problem.

Solution: The grower would need to apply 2,000 × 1.6 = 3,200 lb/acre (1.6 tons/acre) to meet this requirement. This amount may be rounded up or down depending on the accuracy achievable with spreader calibration. *Exact* amounts are not critical, as plants are adapted to a range of soil pH values. However, chronic over- and under-application of lime due to poorly operated and/or adjusted equipment results in disappointing crop responses and lost revenue.

Lime laws differ from state to state, so fineness of grind may be expressed in terms of 2- or 3-sieve rather than 4-sieve analysis as in the example above. In North Carolina, a 2-seive (20- and 100-mesh) analysis is used. While this is less precise for calculating ENV, as in the example above, it is preferable to using CCE alone, which neglects to account for particle size. Also note that, in the example above, the reference ENV is arbitrarily set to 100; in practice, each U.S. state uses specific CCEs and fineness factors to calculate ENV as the basis for lime recommendations. These are published in Cooperative Extension bulletins, along with specific formulas for calculating correction factors. However, the principle ENV = CCE × Fineness Factor is constant across jurisdictions.

3.6 How Much Lime Does A Soil Need?

Low soil pH indicates a need for lime, but it provides no measure of the required amount. The amount needed is called the *lime requirement* and is defined as the amount of aglime needed to raise soil pH to a predetermined "target" based on soil type and the particular crop. The quantitative determination is based on integrating three soil chemical properties: (1) pH, (2) cation exchange capacity (CEC), and (3) base saturation.

The cation exchange capacity of a soil depends on its texture and the amount of organic matter present. The more clay and organic matter there is in a soil, the more lime is needed to change the pH, because soil colloids contain large quantities of exchangeable H^+ and Al^{3+} due to their high CEC. Soils high in clay and organic matter are more resistant to changes in pH (i.e., highly buffered), whereas sandy, low-organic-matter soils require smaller quantities of lime to change pH. Organic (muck) soils contain little exchangeable Al^{3+} and therefore have a lower pH optimum (~pH 5) for plant nutrient availability. In arid and semi-arid regions, soils may be high in clay but need little or no lime.

Base saturation is the quantity of exchangeable basic cations (K^+, Ca^{2+}, Mg^{2+}, Na^+) that are held in the soil expressed as a percentage of the total CEC, or percent base saturation (%BS) for short. The percent of exchangeable non-basic cations (H^+, Al^{3+}) held in the soil is called *exchangeable acidity*. There is a direct relationship between soil pH and the percentage of basic cation saturation. As pH increases, the %BS increases; conversely, as pH decreases, the %BS decreases. *The measure of exchangeable acidity in a soil sample, coupled with the target pH for a specific soil and crop, determines the lime requirement.*

Various methods are used to determine the lime requirement of a soil. One method involves titrating an acid in the soil with a base, $Ca(OH)_2$, to develop a soil titration curve (Fig. 5). This method is highly precise but is

unsuitable for soil testing laboratories that handle large numbers of samples. Such precision is unnecessary given the challenges of pH adjustment in the field. Major field application problems include: (1) natural soil variation, (2) accuracy in calibration of lime spreaders, (3) lime distribution pattern, (4) lime quality, and (5) degree of mixing with the soil.

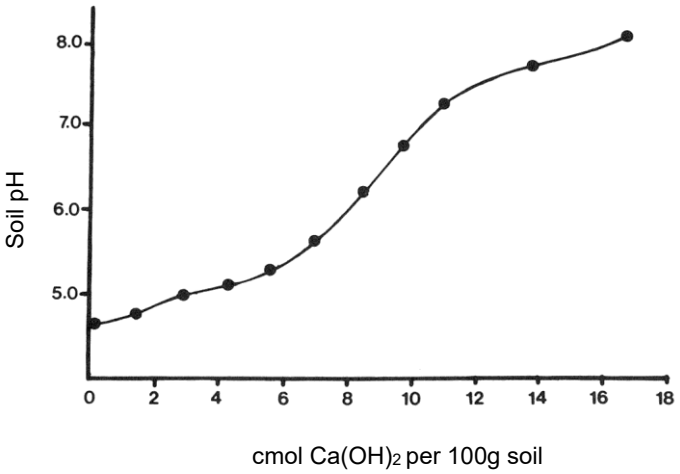


Figure 5 Titration curve for an acid Boswell clay loam soil. A known quantity of lime is added to the soil and change in pH is measured (black dots). Since the soil-lime mixtures must be incubated over several days, this method is time-consuming and not suited for routine soil testing. The amount of lime needed to change soil pH a given increment varies with texture and organic matter content and is related to the soil's buffer capacity; hence many different titration curves are possible. (*source: Adams, 1981*)

Soil testing laboratories have adopted buffered solutions as the quickest and easiest method for estimating lime requirement. The procedure is essentially a titration of soil acidity with a base in the buffer solution. If the buffer's molarity (concentration) is known, the amount of base required to neutralize the buffer's acidity can be determined from the change in pH. Different buffer methods are used in soil testing laboratories in the United States. Some of these are:

- **Woodruff buffer:** developed for prairie soils (Mollisols) limed to pH 6.5
- **SMP (Shoemaker, McLean & Pratt) buffer:** used for high CEC, high-lime requirement Alfisols having large amounts of 2:1 clays, high in organic matter, and large amounts of extractable aluminum.
- **Adams and Evans buffer:** used for low-CEC, low-organic matter red-brown soils (Ultisols) in the southeastern US.
- **Mehlich buffer:** used to determine exchangeable acidity in low-CEC soils; current method in North Carolina.

It is important to remember that the optimal pH varies across crops and soils. Many midwestern soils are limed to a pH of 6.5–7.0. These values would cause micronutrient deficiencies in our southeastern US soils. The reason for this is related to soil genesis. Soils in the southeastern Piedmont and Coastal Plain are more highly weathered; consequently, they have lower concentrations of available micronutrients than younger Midwestern soils. Because micronutrient levels in southern soils are lower, micronutrient availability is more sensitive to pH.

Some micronutrients become less available as the pH increases. For example, manganese deficiency frequently occurs following overliming in many North Carolina soils. Growers submitting soil samples to private soil testing laboratories should ask about laboratory methods and the target pH assumptions used to determine lime recommendations.

Portable soil testing kits are used by some consultants and producers. An inherent weakness of a soil test kit is the lack of an adequate lime recommendation. Some of the more advanced kits include buffers to generate lime recommendations, but they are not adapted to all soils. Lime tables based on soil textural classification and organic matter content are frequently published in popular handbooks. They can be used by an experienced person in situations where laboratory facilities are lacking. Overall, lime tables are the least satisfactory method for determining the amount of lime to apply.

3.7 Practical Pointers

- Soil pH measures acidity but gives no measure of the amount of lime needed to raise pH to a given target value.
- Plants differ widely in their response to lime. When considering a liming program for a given soil, the type of crop to be grown is of primary importance. Information on the optimal soil pH for agronomic and horticultural crops is widely available in popular journals and State Extension publications. Optimal soil pH is typically expressed as a pH range.
- Most agronomically important crops in the Southern USA do best on mildly acidic mineral soils with a pH between 6.0 and 6.5. Liming soils above pH 6.5 is unnecessary and may induce micronutrient deficiencies.
- Organic matter has a high affinity for aluminum. Aluminum tightly bound to organic matter by covalent (ligand) bonding is insoluble over a wide range of soil pHs. High-organic-matter mineral soils have a greater capacity to remove aluminum from solution and buffer its overall effect in acid soils. Organic (muck) soils contain little aluminum and are therefore typically limed to a pH of 5.0 to maximize nutrient availability.
- Lime can be applied at any time of the year. The greatest benefit is obtained when lime is applied several months before planting the principal cash crop. This allows lime to react with the soil, thereby raising the pH.
- Lime recommendations from the NCDA Soil Testing Lab are reported as # lbs (or tons) effective

neutralizing value (ENV) needed to achieve the target pH on ~ 2 million pounds of soil or roughly a 7-inch deep layer over one acre. Because lime is relatively insoluble, it neutralizes acidity only in the zone of application. To be most effective, lime must be uniformly spread and thoroughly incorporated.

- Although lime is spread on the soil surface in no-tillage planting systems, it should be incorporated prior to the adoption of no-tillage to reduce soil acidity. Lime should also be incorporated prior to establishing pastures. The most common method of lime incorporation is the tandem or offset disk. Rotary tillers are more effective at mixing but are limited to small areas due to their low ground speed. Use of the rotary tiller should be restricted due to its negative impact on soil structure.

- The quality of liming material is expressed as ENV rating, which is a product of purity (calcium carbonate equivalence) and the fineness factor. The ENV rating is expressed as the neutralizing index (NI), effective calcium carbonate equivalence (ECCE), or effective neutralizing material (ENM), depending on the state and the reporting laboratory. Don't be confused by these different terms; they are all expressions of lime quality, factoring purity (CCE), and fineness of grind (fineness factor).

- All liming materials are equal in final neutralization of soil acidity when applied at the same rate of ENV and incorporated similarly.

- Most states have laws regulating the quality of materials sold as aglime. Certain composts and industrial by-products have a liming value but are not sold as lime because they fail to meet the legal definition for a liming material. It is always wise to obtain a chemical analysis of soil amendments of uncertain composition (including calcium carbonate equivalence) prior to application.

- The beneficial effects of lime are (1) neutralizing soil acidity, and (2) adding calcium, magnesium, or both elements, in the case of dolomitic lime. Unless soil testing indicates the need to neutralize acidity, lime should never be applied simply to add calcium or magnesium. Crops such as peanuts and subterranean clover that grow best in mildly acidic soils but require supplemental calcium should be treated with neutral salts, such as gypsum (land plaster), that provide calcium without raising pH.

- Soil testing every 2-3 years allows growers to monitor pH and initiate liming before soil acidity reaches a critical level.

- When submitting soil samples to a private laboratory, examine the protocol buffer methods and target pH assumptions used for making lime recommendations.

Further Reading

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