Dirt Hog's Companion

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 passed down from antiquity by the Greeks and Romans who noticed a difference 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 make use of lime in the era 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 the humid regions have developed under conditions in which rainfall exceeds the amount of water used by crops plus losses due to surface evaporation (called *evapo-transpiration*). Soils formed under these conditions are said to be *leached*, and show a gradual depletion of plant-essential basic nutrients (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 measured as a pH value of soil.[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:

o Root and microbial respiration produce CO_2 which dissolves to produce carbonic acid in the soil solution. Carbonic acid is a weak acid, producing H^+ when pH in the soil is above 5 and can be a major source of soil acidity.

o H^+ is released during the decomposition of soil organic matter as the result of mineralization and nitrification.

o Organic acids are released from vegetation, soil organic matter, and plant roots.

o Roots release H^+ or OH^- to maintain electrical neutrality at their surfaces during the uptake of nutrient ions. As such they can be a source of acid or base.

o Soil-forming minerals release H^+ during weathering via contact with acidic rain and soil water.

External sources:

o Rain water. At the moment 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% of the atmosphere) a dilute carbonic acid solution is formed with a pH of 5.6:

$$H_2O \;+\; CO_2 \;\rightleftharpoons\; H_2CO_3$$

water   carbon dioxide   carbonic acid
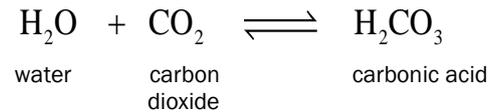
Rain water with a pH different from 5.6 must have other acid or base present. Nitric and sulfuric acid (or ammonia and oxides of N and S) from industrial sources may be dissolved in the atmosphere and cause rain water to have a pH less than 5.6. These are washed into the soil by rain and produce acidity.

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

$$2NH_4^+ \;+\; 4O_2 \;\rightarrow\; 2NO_3^- \;+\; 4H^+ \;+\; 2H_2O$$

ammonium   oxygen   nitrate   acid   water

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:

o Parent materials that are basic (limestone, marl) react with water to give a pH of 7 or higher.

o Ion exchange reactions on clays, and reaction with iron and aluminum oxides, and organic matter remove H^+ from solution in exchange for basic cations.

o 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 was 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:

o Removal of exchangeable basic cations (Ca^{+2}, Mg^{+2}, K^+) by leaching in drainage water and by crops.

o Increase in soluble aluminum (Al^{+3}) at pH < 5.5.

o Phosphorus fixation by aluminum and iron, resulting in phosphorus deficiency.

o Micronutrient deficiency (molybdenum) and toxicity (manganese).

o Reduced root activity and nutrient uptake.

In acid mineral soils, poor plant growth is mainly due to the effect of excessive levels of Al^{+3} 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 acid soil, but not all forms of soil aluminum are harmful to plants. The soluble Al^{+3} ion generated in strongly acid soil is the toxic species. As the concentration of Al^{+3} in the soil solution increases, root growth and function decreases (Figure 1). Root injury is observed at pH 5 and lower. A visual inspection of the root system often shows stubby, truncated lateral roots that are discolored brown or a dull gray color. At low pH and low calcium levels, root membrane permeability is impaired. This makes it difficult for plants to assimilate minerals such as nitrogen, which may be present in plant-available form.
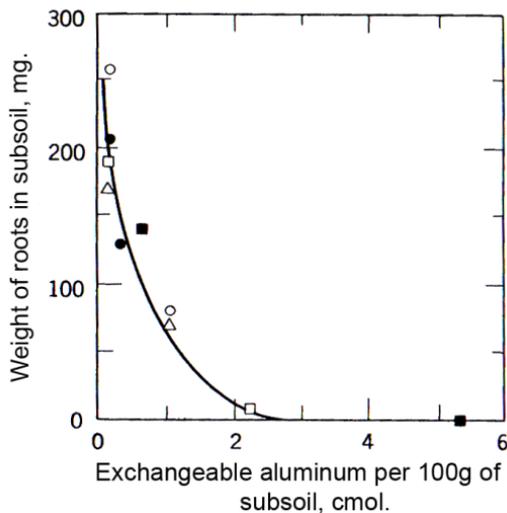

Figure 1 Relationship of root weight and exchangeable aluminum in different subsoils. Legend for subsoils:
• Norfolk; ○ Goldsboro; Δ Lynchburg; □ Rains;
■ Portsmouth. (*source: Ragland and Coleman, 1959*)

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 acid 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 the organic matter content of the soil, either through addition of farmyard manure or crop and cover crop residues, can reduce levels of soluble Al^{+3} and improve plant growth (and has other added 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) is reduced. In general, bacteria tend to predominate in near neutral soil and fungi in acid soil. This shift in the microbiological community can have important effects on soil productivity.
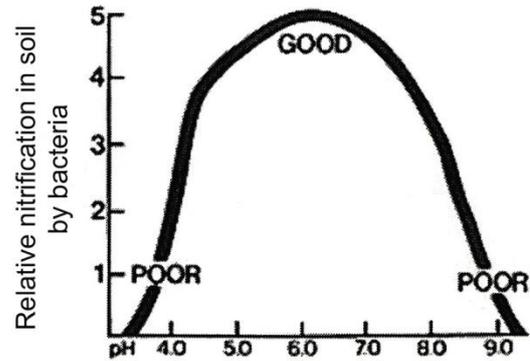
Figure 2 Relationship of soil pH to nitrification.

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 the response of plants to additions of fertilizer P. 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 controling 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 lack of available Mo.
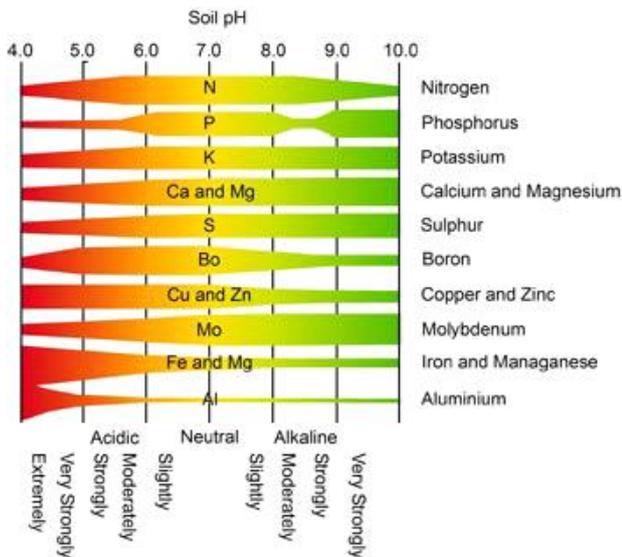
Figure 3 Effect of pH on nutrient availability.
Source: *www.terragis.bees.unsw.edu.au/TerraGIS_soil*

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:

o **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.

o **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, 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.

o **Quicklime** 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 difficult to handle. Quicklime is fast acting and can neutralize soil acidity in a matter of days. It must be thoroughly mixed with soil to be effective. Quicklime reacts with water to produce hydrated lime, using up water at a rate of 30% by weight. It is no longer directly land-applied in agriculture but is employed in construction earthwork to desiccate soil and reduce plasticity of clays (stabilization). It is also widely used in stabilization of fertilizer biosolids and, manure piles to reduce odor and insect problems.

o **Hydrated (slaked) Lime** Hydrated lime is formed by adding water or steam to quicklime. Calcium oxide unites with water to form calcium hydroxide: $CaO + H_2O = Ca(OH)_2$. Hydrated lime is also caustic and fast acting. It is used for making cement and mortar, hence the common name 'builder's lime'.

o **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 the same as in making quicklime. *Basic slag* is formed is 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.

o **Marl** 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 in the form of sand, silt, and clay. *Chalk* is a form of soft limestone found in marine deposits and is chemically similar to marl.

o **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 with soil, and should not come in 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.

o **Manure** Composted manures may contain large quantities of carbonates and thus have a liming value. The actual carbonate content varies with animal and diet. 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. Over use of poultry manure as a fertilizer poses the risk of driving soil pH too high.
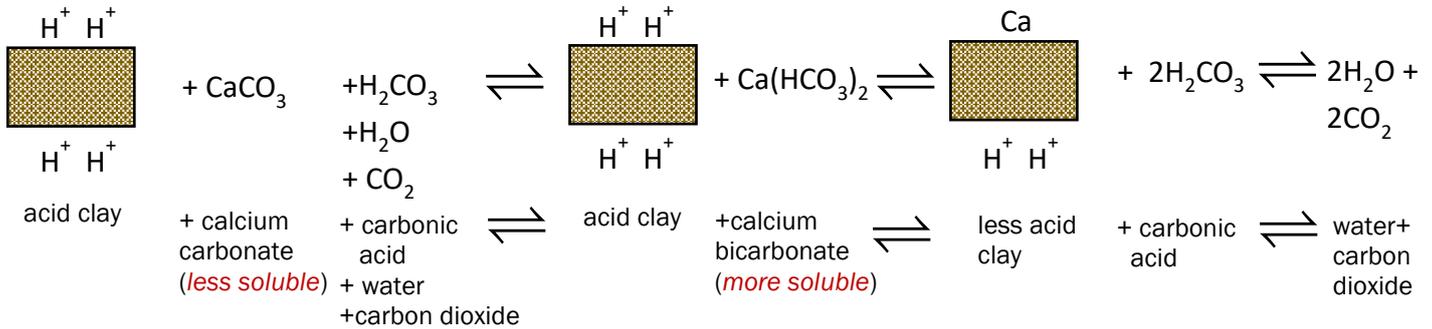
Fluid or liquid lime is prepared by mixing finely ground calcium carbonate with water and a suspending agent (attapulgite clay) so the material can be spread with liquid fertilizer application equipment. The main benefits include: (1) more rapid reaction of lime in the soil due to the finer particle 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.
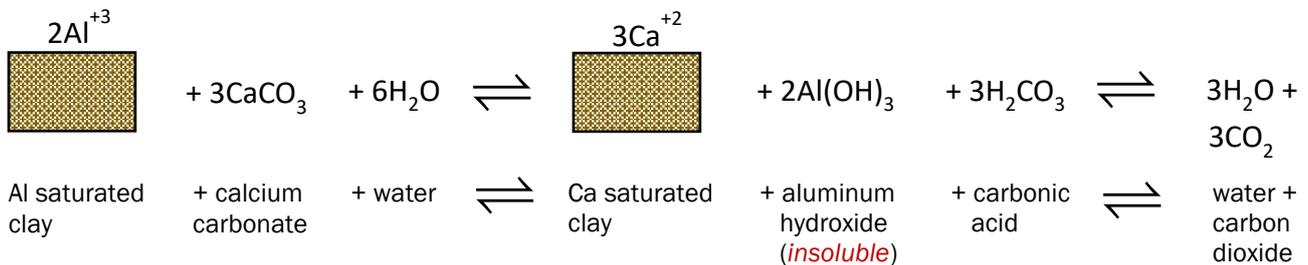
3.4 HOW DOES LIME WORK?

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

$$\text{acid clay} + CaCO_3 + H_2CO_3 + H_2O + CO_2 \rightleftharpoons \text{acid clay} + Ca(HCO_3)_2 \rightleftharpoons \text{less acid clay} + 2H_2CO_3 \rightleftharpoons 2H_2O + 2CO_2$$

acid clay (H$^+$ H$^+$ / H$^+$ H$^+$) + calcium carbonate (*less soluble*) + carbonic acid + water + carbon dioxide $\rightleftharpoons$ acid clay (H$^+$ H$^+$ / H$^+$ H$^+$) + calcium bicarbonate (*more soluble*) $\rightleftharpoons$ less acid clay (Ca / H$^+$ H$^+$) + carbonic acid $\rightleftharpoons$ water + carbon dioxide

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. The calcium bicarbonate ionizes so that its calcium ions are able to replace hydrogen ions on 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 but since more carbonic acid is present than permitted by the CO_2 concentration in the soil air, carbonic acid breaks down to water and CO_2. The overall end result is increased base saturation, increased pH, and a loss of hydrogen ions. Note it is the *carbonates* and *oxides* in lime that actually 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 on clays due to its higher valence (+3) compared to calcium and magnesium.

In acid soils, clays are often saturated with a mixture of hydrogen and aluminum. However, aluminum differs from other cations because it combines with water in a process called *hydrolysis* (literally, splitting of water). Water naturally dissociates to form H$^+$ and OH$^-$ ions. Aluminum combines with the OH$^-$ ions to form 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 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. The calcium in lime can replace exchangeable aluminum on the clay particles if a sufficient quantity is added. This aluminum goes into solution and reacts with water to produce still more 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 presence of H+ ions during the process of soil acidification. The behavior of aluminum in the soil can be very complex, but its reaction with lime can be simplified as:

$$\text{Al saturated clay } (2Al^{+3}) + 3CaCO_3 + 6H_2O \rightleftharpoons \text{Ca saturated clay } (3Ca^{+2}) + 2Al(OH)_3 + 3H_2CO_3 \rightleftharpoons 3H_2O + 3CO_2$$

Al saturated clay ($2Al^{+3}$) + calcium carbonate ($3CaCO_3$) + water ($6H_2O$) $\rightleftharpoons$ Ca saturated clay ($3Ca^{+2}$) + aluminum hydroxide ($2Al(OH)_3$, *insoluble*) + carbonic acid ($3H_2CO_3$) $\rightleftharpoons$ water + carbon dioxide ($3H_2O + 3CO_2$)

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 simple 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 CaCO₃**. Because CCE is expressed in terms of mass, liming materials with a molecular mass *less than* pure $CaCO_3$ have CCE's *greater than* 100 percent, and liming materials with a molecular mass *greater than* pure $CaCO_3$ have CCE's *less than* 100 percent. To determine the CCE of a liming material we simply divide the molecular mass of the material into the molecular mass of the standard, $CaCO_3$:

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

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

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

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

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 for aglime materials but the label must show the amount of the material needed to equal 90 percent CCE. Also, in North Carolina, 90 percent CCE is the basis upon which lime recommendations are made.

The amount of impurities in a lime material will cause its CCE to vary. For example, pure CaO has a CCE of 179%, as noted above. However, impurities in CaO can cause the CCE to vary between 150-179%. 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 CCE's 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 of time. 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 passed through sieves of different mesh diameters. An 8-mesh sieve means that there are 8 openings per linear inch in both directions, or 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_2O. 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 60-mesh reacts in the same time period. Material passing 8-mesh but retained by 20-mesh, and the 20- to 60-mesh fraction are 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	
	% Reacted	
Particle Size	One year after application	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 determine the CCE first, then use the sieve analysis (which expresses the fineness) to calculate the *effective neutralizing value (ENV)* factoring 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 showed a need for 2,000 lbs/acre of lime. The recommendation is based on a minimum 90% CCE 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 to 20-mesh, 21%, 20 to 60-mesh, 25%, and >60-mesh 55%. How much lime should the grower apply?

ENV= CCE x Fineness Factor

The fineness factor is calculated:

$$
\begin{array}{ccccc}
0.10 & \times & 5 & = & 0.5 \\
0.21 & \times & 20 & = & 4.2 \\
0.25 & \times & 50 & = & 12.5 \\
0.55 & \times & 100 & = & 55.0 \\
\end{array}
$$

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 called the *correction factor*, which is used to solve the problem.

Solution: The grower would need to apply 2,000 x 1.6 = 3,200 lbs/acre (= 1.6 tons/acre) to meet this need. This amount may be rounded up or down depending on the level of accuracy that can be achieved with spreader calibration. *Exact* amounts are not critical as plants are adapted to a range of soil pH. However, chronic over-and-under application of lime due to poorly operated and/or adjusted equipment translates to disappointing crop response 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-seive analysis as in the example above. In North Carolina, a 2-seive (20- and 100-mesh) analysis is used. While this is less exact for calculating ENV as was done in the example above, it is still preferable to the use of CCE alone, which neglects to factor in particle size. Also note that in the example above, the reference ENV is arbitrarily set to 100; in fact each U.S. state uses specific CCEs and fineness factors to calculate ENV as the basis for lime recommendation. 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 jurisdications.

### 3.6 How Much Lime Does A Soil Need?

Low soil pH indicates a need for lime, but it gives no measure of the amount needed. 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.

Cation exchange capacity of a soil depends on the texture and 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 change 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 (Tech. Note 6). 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 percent basic cation saturation. As pH increases, the % BS increases; conversely, as pH decreases, the % BS decreases. *It is the measure of exchangeable acidity* in a soil sample coupled with *the target pH for a specific soil and crop* that determines the lime requirement.

There are different methods used in determining the lime requirement of a soil. One method involves titrating an acid, the soil, with a base, $Ca(OH)_2$ to develop a *soil titration curve* (Fig 5). This method is very precise but unsuitable for soil testing laboratories that handle large numbers of samples. Such precision is not needed

because of problems related to pH adjustment on a field basis. 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.
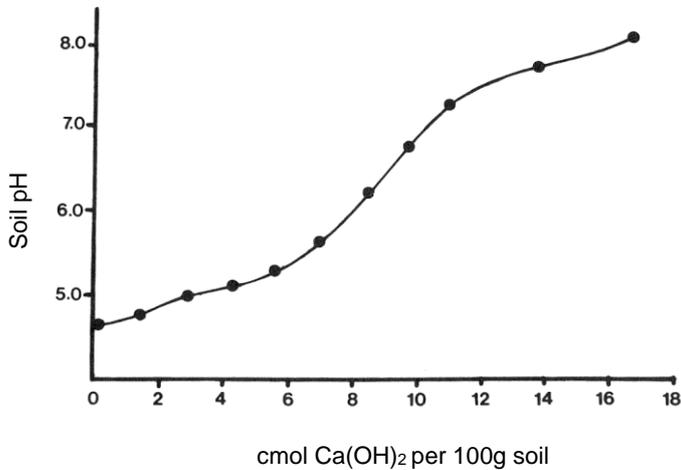
Figure 5 Titration curve for an acid Boswell clay loam soil. A known quantity of lime is added to the soil and change in pH is measured (black dots). Since the soil-lime mixtures must be incubated over several days, this method is time-consuming and not suited for routine soil testing. The amount of 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 the use of buffered solutions to be the quickest and easiest method for estimating lime requirement. The procedure is basically a titration of an acid, the soil, with a base, the buffer solution. The molarity (concentration) of the buffer solution is known and the amount of base required to neutralize the acidity can be determined by the change in pH of the buffer solution. Different buffer methods are used in soil testing laboratories in the United States. Some of these are:

o Woodruff buffer-developed for prairie soils (Mollisols) limed to pH 6.5

o 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.

o Adams and Evans buffer- used for low-CEC, low-organic matter red-brown soils (Ultisols) in the southeastern US.

o Mehlich buffer- used to determine exchangeable acidity in low-CEC soils; current method in North Carolina.

It is important to remember that optimum pH is not the same for all crops or soils. Many midwestern soils are limed to pH 6.5-7.0. These values would cause micronutrient deficiencies in southeastern soils. The reason for this is related to soil genesis. Soils in the southeastern piedmont and coastal plain region are more highly weathered; consequently, they have lower concentration of available micronutrients than younger midwestern soils. Because the quantity of micronutrients in southern soils is lower, availability is more sensitive to pH.

Some micronutrients become less available as the pH increases. For example, manganese deficiencies frequently occur following over-liming in many North Carolina soils. Growers submitting soil samples to private soil test laboratories should *ask questions about laboratory methods and target pH assumptions* used in determining 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 fancier kits include buffers to make 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. But overall, lime tables are the least satisfactory method for figuring the amount of lime to apply.

3.7 PRACTICAL POINTERS

o Soil pH measures acidity but gives no measure of the amount of lime needed to raise pH to a given target value.

o Plants differ widely in their response to lime. In considering the liming program for a given soil, the type of crop to be grown ranks first in importance. Information about optimum soil pH for agronomic and horticultural crops is widely available in popular journals and state extension publications. Optimum soil pH is usually expressed in terms of a range of pH values.

o Most agronomically important crops in the Southern U.S. 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.

o 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 the overall effect of aluminum in acid soils. Organic (muck) soils contain little aluminum thus are typically limed to pH 5.0 for greatest nutrient availability.

o Lime can be applied any time of the year. Maximum benefit is obtained if the lime is spread several months before planting the principal cash crop. This gives lime a chance to react with the soil and raise pH.

o Lime recommendations from NCDA Soil Testing Lab are reported as # lbs (or tons) effective neutralizing value (ENV) needed to achieve target pH on ~ 2 million pounds of soil or roughly a 7-inch deep layer over one acre. Since lime is relatively insoluble, it tends to neutralize acidity only in the zone where it is applied. To be most effective, lime must be uniformly spread and thoroughly incorporated.

o Although lime is spread on the soil surface in no-tillage planting systems it should be incorporated prior to adoption of no-tillage to reduce soil acidity. Lime should also be incorporated prior to the establishment of 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 by low ground speed. Use of the rotary tiller should be restricted due to its negative impact on soil structure.

o 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 differently as: neutralizing index (NI), effective calcium carbonate equivalence (ECCE), or effective neutralizing material (ENM), depending on the state and 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).

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

o 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.

o 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 like peanuts and subterranean clover that grow best in mildly acid soils but need added calcium should be treated with neutral salts like gypsum (land plaster) that add calcium without raising pH.

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

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

Further Reading

Adams, F. 1981. Alleviating chemical toxicities: liming acid soils. *In:* Arkin, G.F. and H.M. Taylor (eds.). Modifying the Root Environment to Reduce Crop Stress. ASAE Monograph 4. St. Joseph, Mich., pp. 297-301.

Adams, F. (ed.). 1984. Soil Acidity and Liming. 2nd Ed. Agron. Monogr. 12. ASA Madison, WI.

Black, C.A. 1984. Soil-Plant Relationships. Krieger Publishing Co., Malabar, FL.

Crozier, C. and D. Hardy. 2017. Soil acidity and liming for agricultural soils. Cooperative Extension Bulletin AG-439-50. https://content.ces.ncsu.edu/soil-acidity-and-liming-for-agricultural-soils

International Plant Nutrition Institute. 2006. Soil Fertility Manual. Norcross, GA.

Ragland, J.L. and N.T. Coleman. 1959. The effect of soil solution aluminum and calcium on root growth. *Soil Sci. Soc. Amer. Proc*. 23:355-357.

Siemens, J.C., Hoeft, R.G., and A.W. Pauli. 1993. Soil Management. John Deere Publ., East Moline, IL.

Wolf, B. 1999. The Fertile Triangle. Haworth Press, Binghamton, NY.

Prepared by: