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Liming Acid Soils in Tennessee

Hubert Savoy Jr., Associate Professor, Biosystems Engineering and Soil Science and
Debbie Joines, Manager, UT Soil, Plant and Pest Center

Soil test results indicate that approximately 40 to 60 percent of the cropland in Tennessee is too acidic for optimum crop production. Because of this, determining the need for lime by soil testing should be the first step in developing a sound crop fertilization program. Lime neutralizes excess soil acids and increases soil pH which is a measure of soil acidity. Levels of extractable aluminum (Al) and manganese (Mn) are reduced to a nontoxic range as soil pH increases. If not limed as needed, soils continue to become more acidic, reducing the potential for production of healthy plants and profitable yields. The need for lime and the optimum soil pH depends upon the type of crop to be produced.

What is Soil Acidity?

Soil acidity refers to the level of acids present in soils. As acid levels increase, the pH of the soil decreases. While the pH scale ranges from 0-14, most Tennessee soils range in value from 4.5 to 7.5. Soils with pH values greater than 7.0 are alkaline or sweet, and those with values of less than 7.0 are acid or sour (Figure 1). As the soil pH decreases below 7.0, the amount of acidity rapidly increases. For example, a pH of 5.0 is 10 times more acidic than 6.0 and 100 times more acidic than a pH of 7.0.

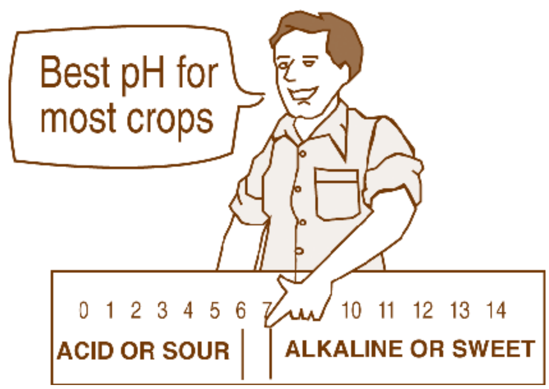

Figure 1. The pH Scale (Source: NCSA).

Causes of Soil Acidity

Several factors contribute to soil acidity. Acid levels increase as basic nutrients (calcium, magnesium and potassium) are replaced by hydrogen through soil erosion, leaching and crop removal. In addition, the use of acid-forming fertilizers greatly enhances acid levels. In particular, the conversion of ammonium (NH_4^+) nitrogen to nitrate ($N0_3^-$) nitrogen in the soil (nitrification) produces significant amounts of acid (H^+) as follows:

$$\text{Ammonium } (NH_4^+) \xrightarrow[\text{Bacteria}]{\text{Oxygen}} \text{Nitrate } (NO_3^-) + \text{Acid } (H^+)$$

As a result, about 3 to 4 pounds of agricultural limestone are needed to correct the acidity formed from each pound of actual nitrogen applied to the soil from either ammonium nitrate, urea, UAN solutions or anhydrous ammonia.

Ammonium sulfate, a common nitrogen material often used in fertilizer blends for its sulfur (S) content, has about twice the acidifying value of those materials listed above and should be used at minimum rates needed to satisfy crop sulfur needs.

Ammonium phosphate's ability to acidify soil is slightly less than that of urea or ammonium nitrate. Commonly used materials include diammonium phosphate or the ammonium polyphosphates used in liquid fertilizers.

Determining the Need for Lime (Water pH)

Soil pH is determined in the University of Tennessee Soil Testing Laboratory with a glass electrode using 10 grams of soil in 10 milliliters of de-ionized water. The value obtained is a measure of the degree of acidity in the soil solution and is used to indicate whether or not lime is needed (Figure 2). It is the value referred to on soil test report forms as water pH.

Determining the Amount of Lime (Buffer pH or Buffer Value)

While water pH indicates the need for lime, buffer pH determines how much to apply. Buffer pH (Figure 2) is a measure of the amount of acid held (adsorbed) by soil particles (clay, organic matter) and accounts for the acid that must be neutralized when lime is added. Buffer pH is reported as buffer value on all UT soil test report forms. The Soil, Plant and Pest Center uses the Moore-Sikora buffer for this purpose.

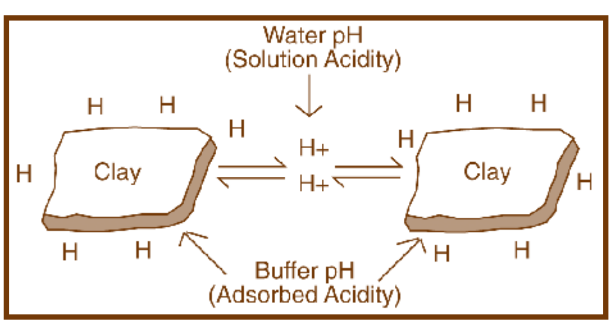

Figure 2. Relation between Water pH and Buffer pH.

The relation between water and buffer pH readings may be more easily understood by considering the relation between the fuel gauge and fuel tank in an automobile. The gauge indicates the relative need for fuel but says nothing about the gallons required to fill up. This measure depends on the size of the tank. For example, if the tank holds 20 gallons and the gauge indicates it to be one-fourth full, then 15 gallons of fuel would be required to refill the tank. If the tank's capacity is 40 gallons, then 30 gallons of fuel would be would be necessary to refill the tank from one-fourth full.

When making lime recommendations, water pH is the "gauge" used to indicate the need for lime, while buffer pH is used to show how much lime should be applied (determines the size of the tank) to properly adjust the soil's pH, or "refill the tank". Clayey soils have more holding capacity or "larger tanks" than silty or sandy soils and may require more lime to produce an equal amount of change in soil pH. Although water pH values may be similar for two or more soils, buffer pH values and recommended lime rates may differ greatly due to different clay levels and amounts of adsorbed acidity.

What Does Lime Do?

Applying lime to acidic soils provides the following benefits:

1. Reduces amounts of soluble aluminum and manganese to non-toxic levels. As soil pH increases, the amount of aluminum and manganese that can be toxic to plants decreases.

2. Supplies calcium, and if dolomitic limestone is used it supplies both calcium (Ca) and magnesium (Mg), which are essential plant nutrients. Also, the availability of secondary and micronutrients is about optimum in the pH range of 6.1 to 6.5.

3. Increases the efficiency of nitrogen (N), phosphorus (P) and potassium (K) use by plants. For example, the efficiency of applied phosphate may be more than doubled when soil pH is increased from 5.0 to 6.1 because of less fixation or tie-up in the soil.

4. Increases the availability of molybdenum (Mo) which is important for nitrogen fixation in legumes such as soybean, clovers, etc.

5. Enhances microorganism activity. Acidic soils slow the growth and multiplication of certain microorganisms, which in turn reduces soil processes such as the release of nutrients from organic matter

decomposition (mineralization) and nitrogen fixation in legumes.

6. Improves the effectiveness of certain herbicides (atrazine, etc.) when used at the right rate of application. Several herbicide families are soil pH dependent. For example, low soil pH levels may reduce the activity or residual time of triazine (atrazine, Sencor) and sulfonylurea (Peak) herbicides. High soil pH levels (> 6.8) tend to increase herbicide activity that can increase the risk of crop injury and/or carryover potential.

7. Increases yields and profits. UT research indicates that 3 tons of limestone applied to soybean fields with soil pH values of 5.1 to 5.5 increased yields an average of 11 bushels per acre. In burley tobacco tests, yields were increased 1,024 pounds when 4 tons of limestone were applied to a soil with pH 4.4.

When and How to Apply Lime

Although lime can be applied whenever soil, weather, crop and labor conditions permit, fall is an excellent time for spreading. Fields are usually dry, lime dealers are less rushed and growers are not occupied with spring planting.

Lime should be spread uniformly. Uneven distribution may present problems for several growing seasons since lime is not applied every year. The interval between soil testing for determination of needed lime applications will vary depending on cropping intensities, soil types, fertilization rates, tillage methods, weather conditions and new research findings (see UT Extension publication PB 1061 "Soil Testing")[(1)].

Lime Sources

The primary function of a liming material is to correct acid soil conditions. Thus, materials (see table 1) that are easily spread and provide the greatest liming value at the least cost are the most desirable. The most common and economical liming material available and used throughout Tennessee is ground limestone. Limestones containing both calcium and magnesium are dolomitic. Those containing mostly calcium are calcitic. When soils are acid and magnesium levels are deficient, a dolomitic limestone should be applied to increase both pH and magnesium levels. Dolomitic limestones sold in Tennessee usually contain about 9 percent or more magnesium.

One of the alternative materials widely available in Tennessee are the lime stabilized biosolids. In certain municipal wastewater treatment plants these are treated with calcium oxide or hydroxide to raise the pH of the biosolids above 12 to kill pathogens. These biosolids contain unreacted calcium hydroxide and can be valuable liming materials even though they don't meet state specifications to be sold as an agricultural liming material. These biosolids should be analyzed for their CCE value and applied at rates not to exceed the lime requirement for the soil to which the biosolids are applied.

The Importance of Limestone Quality

The quality of agricultural limestone is determined by calcium carbonate equivalent and fineness of grind. The calcium carbonate equivalent expresses the maximum percentage of the lime that will eventually become available for soil reaction neutralizing acidity.

Table 1. Liming materials, chemical composition, and calcium carbonate equivalent (CCE).

Material	Composition	Calcium Carbonate Equivalent (%)
Calcium Carbonate	$CaCO_3$ (pure)	100*
Calcitic limestone	$CaCO_3$	80-100
Dolomitic limestone	$CaCO_{3-}$ $MgCO_3$	95-108
Basic Slag (byproduct)	$CaCO_{3-}$ CaO- MgO mixture	variable
Burned or Quick lime	CaO (calcium oxide)	150-175
Hydrated or Slaked lime	$Ca(OH)_2$ calcium hydroxide	120-135
Marl	$CaCO_3$	70-90
Ground Oyster shells	$CaCO_3$	90-100
Cement Kiln dusts	Ca Oxides	40-50
Gypsum**	Ca SO4	None
Byproducts and biosolids	variable	Variable to none

*Calcium carbonate equivalent (CCE) is the acid-neutralizing value for a liming material relative to pure calcium carbonate that has a CCE value of 100. This is the standard method of estimating Agricultural lime purity.
** Gypsum does not affect soil pH but is sometimes used as a source of calcium or sulfur.

Pure calcium carbonate has a calcium carbonate equivalent of 100 and is used as the benchmark by which all other materials are compared. A calcium carbonate equivalent greatly below 100 indicated a considerable proportion of impurities, which usually consist of clay and chert.

Fineness of grind determines the rate[2] that this limestone reacts with soil acids. Limestones coarser than 60-mesh will require a few weeks to several months to produce significant changes in pH, while limestones 60-100 mesh will produce significant changes within two to three weeks when weather conditions are favorable and recommended amounts are applied (Figure 3). Limestones finer than 100 mesh produce results similar to 60-100 mesh materials when applied under similar conditions. Thus, small amounts of "extremely fine" liming materials should not be substituted for recommended amounts of good quality ground limestone. Also, extremely fine materials may be difficult to spread. Agricultural limestones meeting state requirements usually contain adequate amounts of 60-100 mesh material.

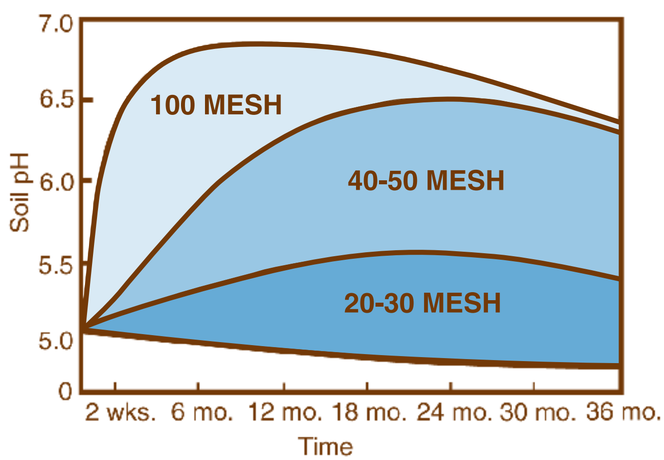

Figure 3. Relation between particle size and rate of change in soil pH when equal amounts of limestone are applied under similar conditions.

Another factor determining the quality of a liming material is its moisture content. The percent moisture content determines how much of the chemically reactive material has been replaced with water. Therefore, higher moisture content reduces the effectiveness of liming materials on a weight basis; i.e., a ton of dry lime will neutralize more acid than a ton of wet lime. However, research suggests that a 4 to 5 percent moisture content in a ground agricultural limestone improves spreading uniformity by reducing the blowing of fine (< 100-mesh) particles as compared to dry (< 1 percent moisture content) liming material. Completely dry material or overly wet material may be more difficult to spread and handle.

Pelletized Lime

Pelletized lime is produced by binding or compressing smaller lime particles into larger granules or pellets. The larger particles are easier to spread and create less dust when handling. For this reason, pelletized lime is often the choice for lawn and garden use. However, if the pellets do not readily slake or break down when in contact with rain or irrigation, their effectiveness in raising soil pH may be reduced. The cost of pelletized lime is usually greater than conventional lime sources because of the added expense in processing. Pelletized lime is sometimes produced from lime that is too fine (200 mesh material or finer) for spreading with conventional equipment. This provides a highly reactive lime material from which a rapid change in soil pH may be expected. In Tennessee, most pelletized lime is produced from standard liming materials and not exceptionally fine materials. The fineness of grind can be noted on the back of bagged materials to determine how reactive the material purchased might be. Generally, the finer the grind, the more reactive the material will be.

State Liming Law (Standard Materials)

The Tennessee Liming Materials Act requires that no liming material be offered for sale that does not have a minimum calcium carbonate equivalent (CCE) of 75 and a relative neutralizing value (RNV) of 65 or greater. The material must be ground so that at least 85 percent passes through a 10-mesh sieve and at least 50 percent passes through a 40-mesh sieve. Calcium carbonate equivalent, fineness of grind values and the relative neutralizing value are required to be indicated in a conspicuous manner on the label or tag of bagged materials and on the delivery slip or invoice for materials sold in bulk.

If the soil test report calls for 1 ton of lime per acre, it is assuming that you are using state certified calcitic or dolomitic limestone, which has a calcium carbonate equivalent of at least 75 and relative neutralizing value of at least 65. If you have a material that has a calcium carbonate equivalent of 150 (hydrated lime), then you need only 0.67 tons to equal 1 ton of agricultural lime or about two-thirds (determined by 100 ÷ 150) as much of this material on your fields as regular limestone because it has a higher neutralizing value. If you know the calcium carbonate equivalent of any material, just divide 100 by that number (100 ÷ X) and

$$\text{Tons } \frac{\text{Lime}}{\text{acre}} \text{ received from soils report} \times \left(\frac{100}{\text{CCE of desired liming material}} \right) = \text{tons lime/acre}$$

multiply it times the lime recommendation of the soils report to determine the amount you need to apply per acre.

This adjustment is already done for lime meeting the minimum state requirement of 75 percent CCE and should only be used when lime materials greatly exceed 100 percent CCE (i.e., quick or hydrated lime) or when using any substandard materials with a CCE much lower than 75 percent (i.e., any material with liming value way below minimum state CCE specifications to be sold as agricultural lime such as lime stabilized biosolids). The desired liming material must meet or exceed minimum fineness of grind values as stated above.

Relative Neutralizing Value (RNV)

The relative neutralizing value of a liming material is determined by calculating the total particle size efficiency and multiplying by the calcium carbonate equivalent as follows:

If the above material had a calcium carbonate equivalent (CCE) of 90 percent, the RNV would be:

88.4 (particle size efficiency) X 0.90 (CCE) = 79

NOTE: Sieve or mesh size refers to the number of openings per linear inch of screen. For example, a 40-mesh sieve contains 40 openings per linear inch or 40 X 40 = 1,600 openings per square inch.

To Compare Materials with Different RNV Values use the following:

RNV (Material No. 1) X 2,000 = pounds of material No. 2 to equal pounds of material No. 1

RNV (Material No. 2)

Percent Material In Each Size Range		Efficiency Factor[2]		Particle Efficiency
5 (coarser than 10 mesh)	x	.33	=	1.6
20 (10-40 mesh)	x	.73	=	14.6
40 (40-60 mesh)	x	.93	=	37.2
35 (finer than 60 mesh)	x	1.00	=	35.0
Total Particle Size Efficiency			=	88.4

Liming No-Till Soils

Lime is very important to no-till crops, especially corn where large amounts of nitrogen fertilizers are applied to the surface without incorporation. The nitrogen tends to produce extremely acidic conditions in the top 2 inches of soil. If not neutralized, the acid will greatly reduce nutrient availability and herbicide activity, resulting in low fertilizer efficiency and poor weed control. Where lime is needed, the same amount is recommended for no-till as for conventional practices. Research does not indicate any advantage to applying smaller amounts more frequently. Soil pH in the top 6 inches may take up to 18 months to reach the desired range but extractable Al and Mn levels are more quickly reduced to nontoxic levels. For this reason, soil sampling in no-till systems is not suggested more frequently than every two years, especially if the reason is to determine changes in soil pH.

If soils are initially extremely acidic (approximately 5.0 or less to several inches), root development and plant growth may be restricted unless the limestone is incorporated into the soil. Surface applications will require more time to neutralize acidity to greater depths than when incorporated into the soil. For pH sensitive crops such as alfalfa, either incorporation or application months to weeks prior to planting may be required for successful establishment and growth on soils with these very low pH values.

Soil samples for determining pH and lime requirement should be collected to a depth of 6 inches for all row and forage crops grown in Tennessee.

References:

(1) Savoy, H. J. and Joines, D. K. 2012. Soil Testing. University of Tennessee Extension publication PB1061. https://utextension.tennessee.edu/publications/Documents/PB1061.pdf

(2) Shaw, W. M. 1960. Rate of reaction of limestone with soils. University of Tennessee Agricultural Experiment Station bulletin. http://trace.tennessee.edu/cgiviewcontentcgi?article=1257&context=utk_agbulletin

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