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Managing Soil Acidity

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What Causes Soil Acidity?

The minerals from which a soil is formed partly determine whether it is acid or alkaline. Soils formed from acidic rocks have a lower pH than those formed from basic rocks or alkaline parent material. Rainfall affects soil acidity development by leaching basic elements such as calcium, magnesium, potassium, and sodium from the soil profile, leaving the acidic elements: hydrogen, aluminum and manganese. In addition, soil erosion can contribute to the loss of basic elements thereby increasing soil acidity.

Management factors such as cropping and fertilizer use also affect soil pH. Removal of harvested crops depletes basic elements from the soil. Nitrogen and phosphorus fertilizers also contribute significantly to the formation of acid soils. Ammonium nitrogen can be a major factor in the acidification of sandy, low buffer-capacity soils, unless a careful liming program is maintained. When ammonium is converted to nitrate by soil microbes, hydrogen ions are released. Anhydrous ammonia, urea and ammonium nitrate each produce an average of 1.8 lbs. of calcium carbonate neutralizable acidity for each pound of nitrogen applied and nitrified in the soil. Ammonium sulfate, which contains two ammonium ions releases an average of 5.4 lbs. of calcium carbonate neutralizable acidity per pound of ammonium nitrogen applied and nitrified.

Soil Acidity Measurement and Ratings

Soil pH is a measure of hydrogen ion (H^+) activity in the soil solution and is used to indicate whether a soil needs a limestone amendment. Soil texture, along with soil pH can be used to estimate the lime requirement of a soil. However, a lime-requirement test (buffer-pH test) is recommended to more accurately predict the amount of limestone needed to raise soil pH in the plow layer to a desired level.

A soil pH in the range of 6.6 to 7.3 (near 7.0) is rated neutral because the pH scale extends from 0 to 14. However, soil pH typically only ranges from about 3.5 to 8.5, unless the soil has been chemically treated or contaminated. Soils are considered slightly acid between pH 6.5 to 6.1, moderately acid between 6.0 to 5.5, strongly acid between 5.5 to 5.1, very strongly acid between 5.0 to 4.5, and extremely acid below pH 4.4. Soils with pH values above 7.4 are rated as alkaline.

Importance of Liming Acid Soils

The most important benefit of liming acid soils is reduction in solubility of the potentially toxic elements hydrogen, aluminum (Al^{3+}) and manganese (Mn^{2+}). The hydrogen ion concentration increases as pH drops below 7.0, but hydrogen only becomes toxic to plants in extremely acid soils (pH<4.0) and at very low calcium levels. As pH drops below 5.5, the concentration of soluble aluminum increases and becomes toxic to plant root growth when it exceeds 1.0 part per million (ppm). Below pH 5.2, the concentration of manganese also increases and can become toxic.

Optimum nutrient uptake by most crops occurs at a soil pH near 7.0. The availability of fertilizer nutrients such as nitrogen, phosphorus and potassium generally is reduced as soil pH decreases (Table 1). Phosphorus is particularly sensitive to pH and can become a limiting nutrient in strongly acid soils. Thus, reduced fertilizer use efficiency and crop performance can be expected when soil acidity is not properly controlled. Soil pH also affects the types, concentrations and activities of soil microorganisms. As pH drops below 5.5, the population of soil microbes changes and is reduced due to aluminum and manganese toxicity and reduced nutrient availability. Fungi tend to become more prevalent in acid soils because they better tolerate acidity compared to bacteria.

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Table 1. Plant nutrient recovery reduced by soil acidity.

Soil pH	Nitrogen	Phosphate	Potash
	Nutrient Recovery (%)		
7.0	70	30	60
6.0	63	15	60
5.5	52	15	45
5.0	38	10	30
4.5	21	8	21

Determining Limestone Quality

Particle Size and the Fineness Efficiency Rating

The speed at which limestone reacts in a soil to neutralize acidity, supply calcium and magnesium, and affect crop growth is largely determined by particle size. Smaller particles have more surface area to contact soil acidity, thereby producing more rapid change in pH. Crushed limestone is screened through a series of sieves to determine its particle size range. Sieve size (mesh) indicates the number of wires per linear inch, thus a larger sieve number represents a smaller particle size.

To allow product comparisons, efficiency factors (as a percent) have been established for different particle size ranges. Efficiency generally indicates what percentage of the limestone will react to reduce acidity within 1 year after application. Table 2 shows efficiency factors (Column B) for four particle size ranges (Column A) used to evaluate efficiency. Particles larger than 2.0 millimeters in diameter (retained on 8 mesh) are given an efficiency factor of zero meaning they do not react with the soil to effectively change pH. As particle size decreases, the rate of reaction increases and reaches 100% for particles less than 0.25 millimeters in diameter (passing 60 mesh). The Efficiency Rating (ER) of a liming material is calculated by multiplying the efficiency factor (Column B) times the percentage of material in a particle size range (Column C). The particle size efficiency rating percentages are summed for all size ranges to determine a products' ER (Column D).

Calcium Carbonate Equivalence

The ability of a limestone to neutralize soil acidity depends upon its calcium carbonate equivalence (CCE), which is expressed as a percentage. Pure calcium carbonate or calcitic limestone is the standard and has a CCE of 100%. All other liming materials are compared with this standard. The CCE of commercial limestone products should be available through the vendor. Some states and/or vendors substitute the term Neutralizing Value (NV) for CCE. Table 3 provides examples of typical neutralizing values for different types of liming materials.

Agricultural limestones used in crop production systems are mainly ground calcium carbonate. Impurities contained in some limestones lower the neutralizing value. Other materials, such as oxides and hydroxides, are products or coproducts of manufacturing processes. Some materials, like hydrated lime, have high neutralizing values, but are difficult and unpleasant to handle in agricultural production systems.

Other Limestone Quality Considerations

Dolomitic limestones come from natural deposits which contain both calcium and magnesium carbonates. The magnesium content of limestone is especially important where soils are deficient in this essential plant nutrient.

Table 2. Calculating the fineness efficiency rating.

Sieve Size (mesh)	(A) Particle Size (mm)	(B) Efficiency Factor		(C) % of Material	(D) Efficiency Rating (%)
Retained on 8 mesh	> 2.0	0	X	10	0
8 to 20	2.0 to 0.85	0.2	X	20	4
20 to 60	0.85 to 0.25	0.6	X	25	15
Passing 60 mesh	< 0.25	1.0	X	45	45
					64%

Table 3. Calcium carbonate equivalence (CCE) of common liming materials and some alternative materials.

Liming Material	Composition	% CCE
Calcium oxide (burnt lime, quick lime)	CaO	179
Calcium hydroxide (slaked lime, hydrated lime)	$Ca(OH)_2$	136
Dolomitic limestone	$CaMg(CO_3)_2$	109
Calcitic limestone (agricultural grade)	$CaCO_3$	85 - 100
Cement dust	$CaSiO_3$	86
Marl	$CaCO_3$	70 - 90
Slags	$CaSiO_3$	60 - 80

Magnesium deficiency in crops and livestock is more likely to occur on deep, acid, coarse-textured, sandy soils which have been intensively cropped. If a soil test indicates low magnesium, dolomitic limestone can be used to correct both the nutrient deficiency and pH. The magnesium in finely ground materials is soluble in acid soils and available for crop uptake.

Since limestone is sold by weight, the percentage moisture it contains is important. Moisture adds weight and will decrease the amount of effective liming material on a ton basis. Agricultural limestones sold at the quarry or stock-piled at retail sites may contain up to 10% moisture, which represents 200 lbs. of water per ton. The limestone rate must be increased to account for the water content at the time of sale and application.

Calculating Application Rates Based on Effective Calcium Carbonate Equivalence

Effective Calcium Carbonate Equivalence (ECCE) combines the fineness efficiency rating (ER) and the calcium carbonate equivalence (CCE) to estimate the percentage of effective limestone in a given product. This is important because rates of limestone recommended by soil testing laboratories to neutralize soil acidity to a desired pH are based on use of 100% effective limestone (dry weight basis).

ECCE is calculated by multiplying the CCE times the ER. For example, assume a vendor has a liming material with an CCE of 94% and an ER of 64% (as calculated above). The ECCE of this material would be:

$$\text{ECCE} = \frac{\text{CCE}}{100} \times \text{ER}$$

$$= 0.94 \times 64$$

$$= 60.0\ \%$$

This means the material would be only 60% as effective as finely ground, pure calcium carbonate. By obtaining from the vendor or calculating the ECCE of a material, the proper rate of application in tons per acre can be determined. For example, if the soil test limestone recommendation is 2 tons of 100% effective calcium carbonate equivalence limestone per acre and the ECCE of the liming material to be applied is 60%, the proper application rate is calculated as:

$$\text{Application Rate (tons/acre)} = \frac{\text{Soil Test Lime Rate}}{\text{ECCE/100}}$$

$$= \frac{2.0\ \text{tons/acre}}{0.60}$$

$$= 3.33\ \text{tons/acre}$$

These simple calculations can be used to compare the economy of various products based on the cost per ton delivered and spread. Table 4 shows the rates of application and per acre treatment costs for four products differing in quality and price.

Table 4. Use of ECCE to calculate limestone rate and compare product cost.

Limestone ECCE (%)	Soil Test Lime Requirement (tons/acre)	Application Rate [Lime required/(ECCE/100)]	Cost per Ton ($)	Cost per Acre ($)
100	1 ton	1 ton / 1.00 = 1.00	35.00	35.00
80	1 ton	1 ton / 0.80 = 1.25	32.00	40.00
60	1 ton	1 ton / 0.60 = 1.67*	29.00	48.43
50	1 ton	1 ton / 0.50 = 2.00	26.00	52.00

** If one ton of limestone per acre is recommended and the liming material to be used has an ECCE of 60%, then the application rate of this material would be 1 ton divided by 0.60 =* ***1.67 tons/acre****.*

Effective Liming Material

Another way to compare the value of limestone is to calculate the amount of effective liming material (ELM) in a product. The pounds of ELM in a ton of limestone can be determined by multiplying the ECCE of the limestone by 2000. For example, if the ECCE of a limestone is 60%:

$$\frac{60}{100} \times 2{,}000 = 1{,}200 \text{ lbs. of effective limestone per ton}$$

This indicates that the product contains 1,200 lbs. of effective liming material that will function to neutralize acidity and raise soil pH. The calculation also demonstrates that this product contains 2,000 - 1,200 = 800 lbs. (40%) of ineffective limestone or other foreign material which will not react to raise soil pH.

Suggested Limestone Application Rates

The amount of limestone needed to adjust soil pH to a desired level for a particular crop depends on the initial soil pH, soil clay content and soil buffer capacity (resistance to pH change). Testing soil pH is an excellent indicator of the need for lime and in combination with soil texture is sometimes used to estimate lime requirement. However, most soil testing laboratories offer a buffer lime-requirement test that provides a more accurate estimate of the quantity of lime which should be applied. Tables 5 and 6 present suggested limestone rates for grasses and legumes based on soil pH and texture.

Soil Sampling: Methods, Timing and Frequency

Collecting a soil sample for pH, lime requirement and plant nutrient analysis is the first and most critical step in determining lime and fertilizer needs. Improper sample collection and handling invalidates test results and can lead to incorrect recommendations. For each soil series in a field, collect at least 15 samples from the 0 to 6-inch depth at random locations across the site and place them in a clean, plastic bucket. Avoid abnormal soil areas that do not represent a significant acreage, or sample them separately. When sampling is complete, mix these samples thoroughly,

Table 5. Minimum suggested limestone rates for grasses based on soil texture and pH.

pH Range	Sands and Loamy Sands	Sandy Loams	Clays and Clay Loams
	Tons of Limestone/Acre[1]		
Greater than 6.0	0	0	0
5.5 to 6.0	1.0	1.0	1.5
5.0 to 5.4	1.5	2.0	2.5
4.5 to 4.9	2.0	2.5	3.5

[1]Based on use of 100% ECCE limestone. Divide the recommended rate by the ECCE of the liming material to be used (as shown in Table 4) to determine proper application rate.

Table 6.Minimum suggested limestone requirements for legumes based on soil texture and pH.

pH Range	Sands and Loamy Sands	Sandy Loams	Clays and Clay Loams
		Tons of Limestone/Acre[1]	
Greater than 6.5	0	0	0
6.0 to 6.4	0.5	1.0	1.5
5.5 to 5.9	1.0	1.5	2.0
5.0 to 5.4	2.0	2.0	3.0
Lower than 5.0	2.5	3.0	4.0

[1]Based on use of 100% ECCE limestone. Divide the recommended rate by the ECCE of the liming material to be used (as shown in Table 4) to determine proper application rate.

then place about one pound of the soil in a sample bag. Repeat the process for each soil series in the field. For deep-rooted crops, an additional composite sample collected at the same time from the 6 to 12-inch soil depth will help evaluate subsoil pH conditions. If samples will not be delivered to the soil testing laboratory immediately, spread them on nonporous paper plates to air dry before shipping. Record the field identification, sample number, and name and address of the owner on the sample bag. Complete the soil sample information sheet, providing all requested information about the field and crop to be grown, and keep a duplicate copy for your records.

Timely soil sampling is important because limestone requires both soil moisture and time to neutralize soil acidity. Early sampling and limestone application several months in advance of crop growth provide time for pH adjustment. In addition, soil pH fluctuates during the year becoming lowest in the fall, in part as a result of fertilizer applications and plant removal of bases. Thus, fall soil sampling may provide a more accurate estimate of the minimum pH that will occur in a field. Frequency of soil sampling to determine lime requirement will depend on soil properties, crop, and the source and amount of nitrogen applied. Under intense grass production using high rates of nitrogen fertilizer, sandy soils will rapidly increase in acidity. Sampling at least every other year is recommended.

Timing of Limestone Application

Although limestone can be applied at any time, several factors should be considered when planning an application. Soil moisture is critical to the reaction of limestone, thus rainfall patterns in the area should be used as a guide. Soils should be sufficiently firm to support heavy equipment and minimize compaction. If subsoil pH is low, a long period will be required for the limestone to begin to effect a change in the soil pH with depth. In addition, coarse limestone reacts more slowly and, as with all limestones, is most effective when incorporated into the soil. When a more rapid and longer lasting pH adjustment is needed, the use of finely ground limestone is advisable.

Methods of Application

Dry bulk limestone is typically applied using fertilizer spreader trucks. The density of the spreading pattern declines with increasing distance to the side of the truck. In addition, minimizing dust and achieving a uniform spreading pattern can be increasingly difficult with finely ground limestone products. A moisture content of 7 to 10% in fine limestone is needed to minimize dust and achieve a uniform spreading pattern.

Liquid, fluid or suspension lime is a combination of very fine limestone (100 mesh or smaller) in water with 1 to 2% clay to form a suspension that is about 50 to 60% solids. The material is typically spread using a tank truck equipped with a boom and high-volume nozzles. With proper calibration, this enables very uniform product application with no dust. Like all liming materials, to be most effective fluid/suspension lime should be incorporated into the soil.

Fluid lime does not react differently than finely ground dry limestone of similar neutralizing value and particle size. At 60% solids including 2% clay, one ton of fluid lime will provide 1,160 lbs. of acid-neutralizing limestone that is as effective as the limestone used to make the suspension. Thus, approximately 1.72 tons of fluid lime (product) would be required to provide the same quantity of acid-neutralizing lime as one ton of dry lime of equivalent quality. Fluid lime is usually more expensive per ton than limestone applied dry due to increased costs for finely ground materials, freight and product application. Although fluid lime reacts rapidly in the soil because of its extreme fineness, its long-term effectiveness for neutralizing soil acidity is similar to dry liming materials that have an ECCE = 100%. Nitrogen solutions or other fluid fertilizers have been used instead of water for suspending fluid lime and can reduce the total cost of application. However, caution should be used since a small amount of calcium oxide or calcium hydroxide in the liming material results in a pH above 8.5 which can cause loss of nitrogen as ammonia gas during application. Phosphorus fertilizer should not be mixed with liming material due to possible reactions which can reduce phosphorus solubility and plant uptake.

Summary

- Soil acidity is caused by removal of basic elements through leaching and crop uptake, organic matter decomposition, acid rain, nitrification of ammonium-nitrogen, and by natural soil forming processes.
- Soil acidity is estimated by pH and ranges from 3.5 to greater than 8.5. A pH of 7.0 is neutral.
- Soil acidity reduces plant nutrient availability and increases aluminum and manganese toxicities.
- Neutralizing value and fineness determine the effectiveness of limestones for raising soil pH.
- Finely ground limestones are least costly for neutralizing soil acidity.
- The lime requirement of an acid soil may be estimated from soil pH and soil texture, but is most accurately determined by a buffer lime-requirement test.
- Proper soil sampling is critical to obtain accurate limestone recommendations.
- Timely limestone application and incorporation into the soil are important factors in correcting and managing soil acidity.

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[Note: A more complete and detailed discussion of soil acidity and liming can be found in the technical publication “Liming Acid Soils” (See Haby, V.A. et al., 2001. TAES Bulletin No. B-1720) or visit the web site at http://overton.tamu.edu (click on “soils”).]

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