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Land Reclamation

Jeff Skousen, *Professor and Land Reclamation Specialist, WVU Extension Service*
Louis McDonald, *Division of Plant & Soil Sciences, WVU*

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Liming Principles and Lime Products

What is an Acid Soil?

A soil is called acid when soil pH is <7.0. Soils can also become acid as elements such as calcium (Ca^{+2}) and magnesium (Mg^{+2}) are leached from the soil profile in humid areas. This soil leaching gradually replaces soluble salts and basic cations with exchangeable hydrogen (H^{+}), and various forms of hydrated aluminum and iron compounds (Figure 1). Leaching with rainfall can gradually dissolve silicate clays releasing silica and more aluminum and iron. A soil may be naturally acid because it was formed from acid rock parent material containing little or no limestone. These acid-producing minerals are commonly associated with coal seams and coal outcrops along hillsides.

Types of Soil Acidity

Several forms of acidity can be found in soils and they all influence the lime requirement (LR) of a soil. The four forms of acidity are called active, replaceable, residual, and potential. Each of these acidity forms tend to react sequentially as a lime material is added to soil, therefore different methods are used to measure each form.

Soil pH or sometimes called "Active" acidity relates to the concentration of H^{+} ions in the soil solution and can be measured directly by a pH meter. This form of acidity is a very minor part of the total acidity and is easily and quickly neutralized with lime.

Salt-replaceable (or sometimes referred to as "Exchangeable") acidity is correlated to aluminum, iron, and hydrogen loosely associated with the surfaces of soil particles (Figure 2). These elements are replaced by flushing the soil with a salt solution containing potassium chloride (KCl), which replaces these acid cations with potassium on the surface exchange site. Then the displaced acid cations can be measured.

Residual (also called "Non-exchangeable) acidity is also due to aluminum, iron, and hydrogen, but these elements are more tightly held to the surface of soil particles. A stronger base, which causes a higher pH of 8.2, is used to replace these elements. Limestone can neutralize this acidity, but not unbuffered salt solutions. The acidity neutralized at pH 8.2 corresponds to complete neutralization of these acid cations in the soil solution and on the exchange sites.

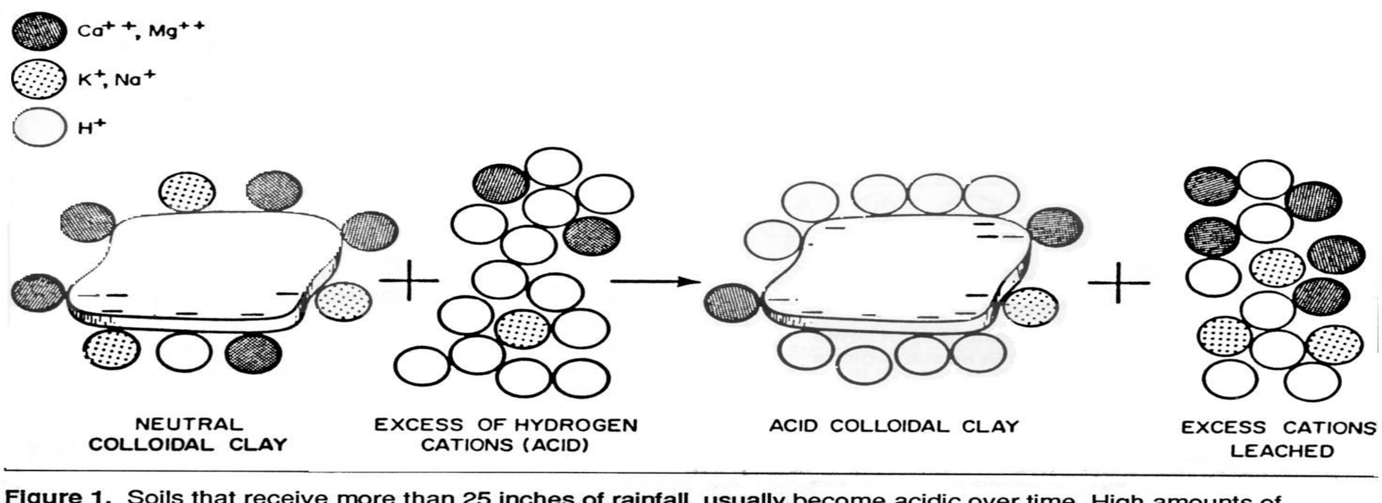

Figure 1. Soils that receive more than 25 inches of rainfall usually become acidic over time. High amounts of precipitation gradually leach calcium and other bases from cation exchange sites (represented by the negative signs on the soil particles) with replacement by acidic cations. (Source: Donahue et al. 1977).

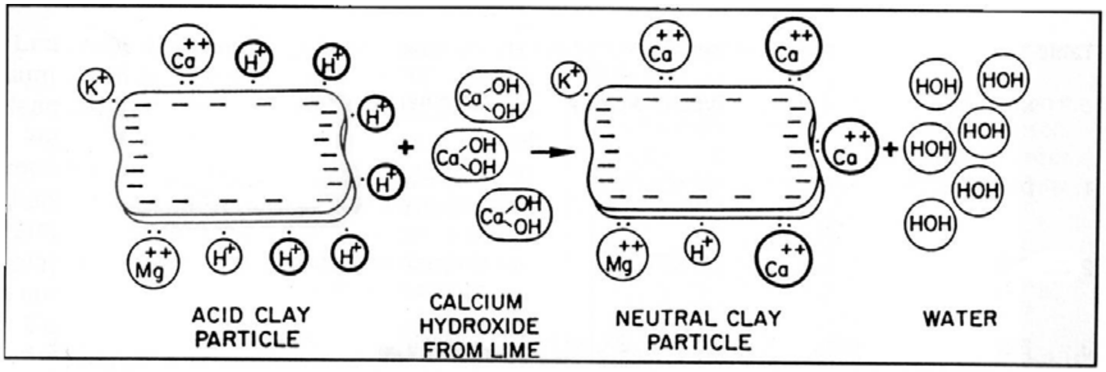

Figure 2. Lime neutralizes acidity and adds calcium to soils. In this example, hydrogen ions (H^+) from the exchange sites combine with hydroxide ions (OH^-) supplied by calcium hydroxide to form water. Calcium (Ca^{+2}) replaces the H^+ on the exchange sites. In the same way, aluminum ions(Al^{+3}) on the exchange sites react with OH^- to form insoluble aluminum hydroxides ($Al(OH)_3$) as pH increases above 5.5. (Source: Donahue et al. 1977).

Potential acidity results from oxidation of unweathered parent materials like pyrite. When unweathered sulfide-bearing minerals are brought to the surface, they undergo rapid reaction and release high amounts of iron and hydrogen over time. The lime needed to neutralize this acid can be very high depending on the pyrite content of the material and the oxidation rate.

How is the LR Determined for Acid Soils?

The lime requirement (LR) of an acid soil is the amount of lime needed to neutralize the acidity from an initial condition to some target soil pH, like 7.0. Different methods are used to calculate a LR for specific soils. Lime requirement tests will always recommend adding enough lime to neutralize all the acidity associated with soil pH, much of the salt-replaceable acidity, and some of the residual acidity. Other methods are used to estimate the amount of lime to neutralize potential acidity.

Table 1 summarizes common methods used to measure different types of soil acidity and to determine LR. The most common methods for determining LR are Incubation and Buffer techniques. The other methods in Table 1 are specific to soil survey work and mine reclamation.

Extraction techniques employ the use of a salt solution, which is poured into a column containing soil. The leachate is collected and analyzed to determine pH and elemental concentrations, and the LR is determined based on the amount of hydrogen, aluminum, and iron that is displaced by the salt solution.

Incubation methods involve adding increments of a base such as calcium hydroxide ($CaOH_2$) to a soil suspension, allowing the mixture to equilibrate for a period of time, and then measuring soil pH. The results are displayed on a graph and the curve levels off at a pH of 8.2, which indicates calcium saturation of exchange sites and neutralization of acidity. Because the time required to reach equilibrium at each incremental addition can often take weeks, this method is time-consuming and not used for routine LR determinations.

Buffer methods use a fast-reacting, weak liming agent that is added to a soil sample. The mixture is allowed to equilibrate, and the pH is measured. The LR is read directly from a table based on the pH of the soil after the buffer has been added: the lower the pH of the mixture, the higher the LR (Table 2). The table is developed from years of data relating soil response to liming in that particular area. Buffer techniques are the most commonly used LR test in the US, and different buffers are used in different areas based on the dominant soil minerals of the area. For example, a soil sample sent to a laboratory in Colorado would probably give a different LR than if that same soil was analyzed in West Virginia because different buffers are used.

What Method Should Be Used?

The Buffer techniques are good methods for LR determination where soil testing laboratories have correlated the response for liming to these soils. If unweathered sulfide minerals exist in your soils or you suspect that that your soils may be disturbed, a Buffer method and Acid-Base Accounting should be conducted on the sample.

Table 1. Common methods used to measure soil acidity.

Method	Comments
1. pH meter - Only measures soil pH and is not used to determine LR by itself.	
2. Extraction Techniques	
	KCl - Gives an estimate of exchangeable aluminum and hydrogen only.
	$BaCl_2$ - TEA Widely-used in soil survey, but usually overestimates LR for most soils.
3. Incubation - Requires a great amount of time to allow the soil-water-base suspension to equilibrate.	
4. Buffer Techniques	
	Mehlich - Several different formulations of this strong acid technique are used. The WVU Soil Testing Laboratory uses the Mehlich III method.
	SMP - Schumacher-McClean- Pratt were the names of the scientists that developed this extraction fluid. Used in Midwestern US soil testing laboratories
	Woodruff - This buffer technique was developed for calcareous soils and is used extensively in arid Western US soil testing laboratories.
5. Acid-Base Accounting	
	This laboratory procedure measures both the acid-producing (potential acidity) and acid-neutralizing materials in soils. It is not generally used by itself to determine LR.
6. H_2O_2 Oxidation	
	Another method used in a few laboratories to measure potential acidity, especially those containing unweathered pyritic materials.

Table 2. Lime requirement in tons per acre is determined by the pH of the soil solution after a buffer solution has been added. The WVU Soil Testing Laboratory uses the Mehlich III buffer to determine LR for West Virginia soils.

pH	Lime Requirement (tons/acre)
6.5	0.4
6.3	1.2
6.0	2.4
5.8	3.2
5.5	4.4
5.2	5.6
5.0	6.4
4.7	7.6
4.5	8.4

Benefits of Liming

Lime neutralizes soil acidity and adds calcium, a macronutrient essential to plant growth. Maintaining the soil pH between 6.0 and 7.0 by liming is recommended since this is the range where plant nutrients are most available and toxic elements are less available. Liming also improves the environment for most soil microorganisms, which promotes a more rapid breakdown of organic matter to release plant nutrients. It especially aids in enhancing the spread of legumes in pastures like clovers, trefoil, and alfalfa.

Lime Sources and Quality

The most common source of lime is ground limestone ($CaCO_3$), which is readily available in West Virginia. Other liming materials are listed in Table 3.

These other materials can be less or more expensive depending on the source and transportation costs. The actual analysis of the material must be checked before purchasing or applying to the field. The supplier is required to disclose the analysis of the material and to give its CCE value (Figure 3). If in doubt and there are questions concerning the material's source, CCE, or purity, do not use it even if the price seems low. As the quality of the material decreases, more material must be applied to get the same neutralizing power (see calculations below).

The fineness or particle size of the liming material is very important. Finer particles react faster because more surface area can contact the soil and be exposed to water. Finely ground limestone (100-mesh size) tends to react and raise pH within several weeks after application, whereas larger particles (larger than 20-mesh) can take one to three years for increases in soil pH to be realized. For best results, >90% should pass a 100-mesh sieve to raise pH within 2-3 months. For good results, 95% of the

Table 3. Common names of liming materials, their chemical formulas, and calcium carbonate equivalent (CCE).

Neutralizing Material	Chemical Formula	CCE	Average Purity
Limestone, calcium carbonate, calcite	$CaCO_3$	100	85-95%
Burned lime, quicklime, calcium oxide	CaO	179	95-98%
Slaked lime, hydrate, calcium hydroxide	$Ca(OH)_2$	136	90-98%
Dolomitic limestone, dolomite	$CaMgCO_3$	110	80-90%
Magnesium carbonate	$MgCO_3$	119	85-95%
Slag, blast furnace slag, steel slag	$CaSiCO_3$	50-90	60-90%
Marl, bog lime, burned oyster shells	$Ca\ CO_3$	60-80	50-70%

limestone should pass a 20-mesh sieve, 75% should pass a 60-mesh sieve, and 60% should pass a 100-mesh sieve. This particle size information should be listed on the lime bag or be guaranteed by the supplier. Anything that lists <50% passing a 100-mesh sieve is suspect. This can be actually checked by feeling the material. The lime should be the consistency of flour.

Liming Practices

Lime can be applied at any time, but lime takes time to dissolve and neutralize soil acidity. For this reason, we recommend liming about 3 to 6 months before planting crops, and especially crops with a high pH requirement (such as legumes). Fall applications are beneficial because they allow the lime to dissolve before the next growing season. Apply and incorporate lime a month or more before adding fertilizers, since the lime may interfere with the availability of fertilizer nutrients, especially phosphorus (Figure 4).

If the liming rate is 3 tons or less, the lime can be surface applied and rainfall will gradually move the lime into the soil. For maximum benefits, lime could be incorporated and mixed into the top 3 to 6 inches of the soil. Incorporating and mixing is especially critical where the soil pH is <5.0 and a large quantity of lime is applied (>5 tons/ac). On most soils, 3 to 5 tons per acre is the highest rate normally recommended for surface application.

Lime Program in West Virginia

Most native soils in West Virginia have a naturally low pH of 5.3 to 5.8. Lime is needed to raise the pH for pasture, hay and cropland for production. In 2005, the West Virginia Legislature approved a Lime Incentive Program, which encourages the spreading of lime on agricultural land in the state, especially on those areas that have recently been taken out of production and may have returned to unmanaged grasslands or may be invaded by shrubs and trees.

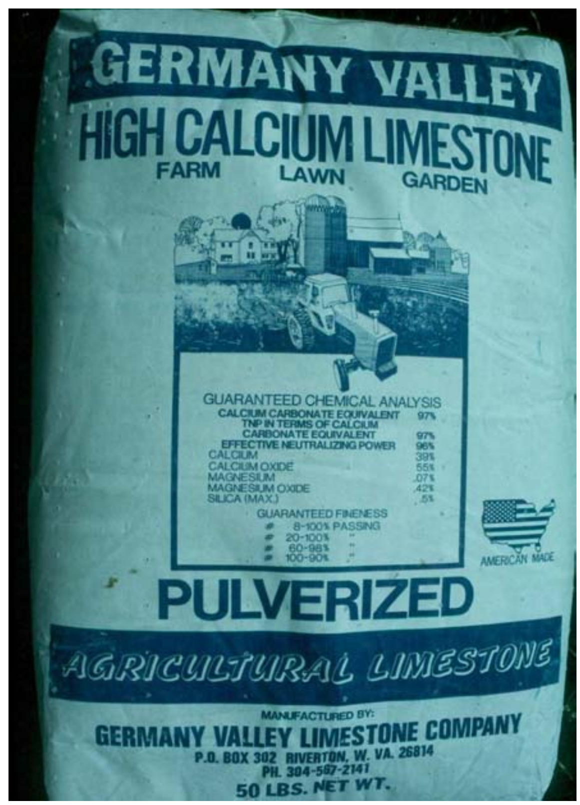

Figure 3. *Each supplier of lime products must provide the quality of the limestone material sold. This label provides the calcium carbonate equivalent (CCE) of the material and also gives the particle size of the material by expressing the percentage of the material that passes specified sieve or mesh sizes.*

With this renewed interest and funding for lime application, alternative lime products are sometimes suggested as substitutes for ground agricultural limestone. Again, we recommend the use of ground agricultural limestone with CCE values and purity that can be guaranteed. A small particle size as that suggested in this article must also be assured.

If someone encourages the use of an alternative lime material due to its low cost, do a few calculations to see if the material will actually save you money or neutralize acidity in the soil.

Figure 4. *Lime can be spread at any time during the year, but late summer and fall are often good times to apply lime. Lime spreaders apply lime evenly over the soil. Some spreaders are pulled by a tractor, while other spreaders may be mounted directly on trucks.*

Calculations

Assumptions:

Amount of lime recommended by a soil testing laboratory = 3 tons/ac
CCE of a special lime material = 72%
Particle Size of the Material = 50% passes 20-mesh sieve
Cost of special lime material = $2 per ton
Cost of 100% CCE agricultural lime = $4 per ton

Since the liming material is only 72% CCE, 4.2 tons per acre of this material must be applied to achieve the 3 tons per acre recommended lime rate to neutralize the soil acidity.

3 tons per acre / 0.72 = 4.2 tons per acre

Since only 50% of the material is small enough to react in the soil, the other 50% will take many years to break down and neutralize acidity and is therefore useless in the short term. So instead of applying 4.2 tons per acre of this material, the rate would have to be doubled to get the amount of lime that will react in your lifetime to neutralize acidity.

4.2 tons per acre / 0.50 = 8.4 tons per acre

If the price of this special lime is half the price of ground agricultural limestone (which you may have thought was a bargain), the real cost of the special lime material would be almost $17 per acre compared to the $12 per acre with ground agricultural limestone. Plus, additional transportation costs will be incurred because more of the special lime material is needed to get the same neutralizing value as ag lime.

Special Lime 8.4 tons per ac x $2 per ton = $16.80 per acre
Ag Lime 3.0 tons per ac x $4 per ton = $12.00 per acre

Transportation costs may be a set rate at $10/ton of material, so the additional material needed when using the special lime will cost much more to transport to your site.