Extension FactSheet
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Soil Acidity and Liming for Agronomic Production

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Soil pH is an important consideration when producing any crop, and soil pH should be the first soil consideration when attempting to grow a plant. Soil pH affects soil microbial activity and populations, many soil chemical reactions, and nutrient availability; thus it is an important soil property to consider for maximum productivity.

pH is a measure of the hydrogen (H^+) ion concentration in solution. Due to the way pH is calculated, the higher the hydrogen concentration, the lower pH becomes. A pH value below 7.0 is considered acid and, depending upon the soil pH and the crop being grown, may require neutralization to raise the soil pH. High concentrations of hydrogen in soil solution (low soil pH) may cause the release of soluble aluminum from soil minerals. Aluminum in soil solution binds with phosphorus (decreasing phosphorus availability to plants) and inhibits root growth and development (limiting nutrient uptake). Low soil pH also limits the release of some nutrients from soil organic matter and reduces nitrogen fixation by legumes. However, soil does not have to be neutral (pH 7.0) to maximize nutrient uptake or crop production. For example, legumes require pH levels of 6.2 or higher, but corn can be productive in soils with pH levels as low as 6.0. Additional information on soil pH may be found in the *Ohio Agronomy Guide*.

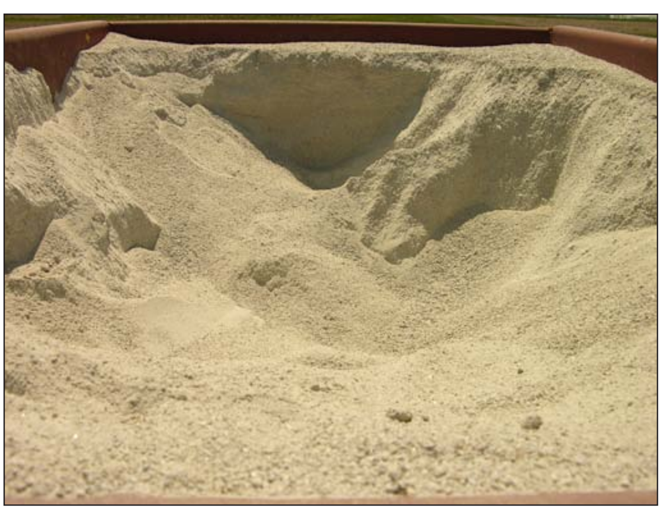

Figure 1. Photograph of typical aglime.

Causes of Soil Acidity

Soil parent material and the climate under which a soil was formed are important determinants of soil acidity. Soils that developed from parent materials low in carbonate minerals (calcium/magnesium carbonates) are usually acidic. Soils in eastern Ohio are derived mostly from sandstone and shale parent material that are low in carbonate minerals and are likely to be acidic. Soils of western Ohio are mainly derived from glacial deposits rich in calcitic (calcium carbonate) and dolomitic (calcium-magnesium carbonate) minerals and are less likely to be acidic (Ohio History Central, 2005). Soils that form under high rainfall (conditions like those in Ohio) are subject to extensive chemical weathering and leaching of basic cations that are replaced with H^+ and other acidic cations (Al^{3+} and iron [Fe^{3+}]). These basic cations include calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+), and sodium (Na^+). Over time, this continuous removal of basic cations is faster than is their replacement from weathering minerals, resulting in acid soil conditions.

High yielding crops, applications of certain forms of nitrogen, and other agricultural practices also contribute to soil acidity. Roots of high-yielding grain and forage crops remove basic cations from the soil and release hydrogen into soil solution to maintain an ionic charge balance within the tissue. Ammonium-based fertilizers release hydrogen when oxidized to form nitrate, contibuting to soil acidity. The amount of lime required to neutralize the acidity created by various nitrogen fertilizer materials is given in Table 1.

Table 1. Pounds of calcium carbonate equivalent lime needed to neutralize acidity produced by application of various nitrogen fertilizers (nitrogen rate of 100 lb N/A) (adapted from Havlin et al., 1999).

Fertilizer source	Fertilizer source application rate (lb/A)	Equivalent lbs of lime/A
Anhydrous ammonia (82-0-0)	122	180
Ammonium nitrate (34-0-0)	294	180
Ammonium sulfate (21-0-0)	476	540
Urea (46-0-0)	217	180
Monoammonium phosphate (MAP)	821	540
Diammonium phosphate (DAP)	476	360

Soil Sampling and Testing to Determine Soil pH and Lime Requirement

Soil pH measurement is a routine analysis conducted on almost any soil sample submitted to a soil testing laboratory. For tilled soils, soil samples should be collected to a depth of 8 inches, and for no-till soils samples should be collected to a depth of 4 inches. Soil water content and resulting salt concentration at the time of soil sampling can affect pH measurements. Avoid collecting soil samples when the soil is excessively dry or wet. Soils sampled during a dry period may result in lower pH values, and conversely, soil samples collected during an excessively wet period may result in higher pH values. Because soil pH levels change slowly in a natural setting, soil analysis does not need to be conducted every year. Soil testing performed every two to four years should be adequate.

Soil pH measurement reveals the amount of active acidity (free hydrogen ions) in the soil solution and whether or not lime should be applied. If the soil pH level is below the optimum for the desired crop, liming may be necessary (Table 2). In order to accurately determine the amount of lime necessary to neutralize soil acidity to the desired level, the buffering capacity of the soil must be measured. Buffer pH measurement reveals how much potential acidity needs to be neutralized by the lime. Potential acidity refers to the hydrogen and aluminum cations that are held by soil exchange sites. As buffer pH decreases, the amount of lime required to neutralize both active and potential acidity increases. Soils with an abundance of exchange sites (high buffering capacities) have a greater supply of H^+ and Al^{3+} than soils with fewer exchange sites (low buffering capacities). Fine textured soils (clay) typically require higher rates of lime than coarse textured soils (sands). Soils that have high buffering capacities also require less frequent application of lime than soils with low buffering capacities (i.e. coarse textured soils are likely to require lime more frequently). Coarse textured soils should also be sampled more frequently than fine textured soils to determine lime need.

Actual buffer pH is a measurement often reported by soil testing laboratories, but another term has also been used—lime test index (LTI). Lime test index is simply buffer pH multiplied by 10.

Table 2. Recommended topsoil pH (to a depth of 8 inches for tilled soils and to a depth of 4 inches for no-till soils) for various crops on mineral and organic soils (adapted from Tri-State Fertilizer Recommendations, 1996).

	Mineral soils with subsoil pH		
Crop	pH > 6	pH < 6	Organic soils
Alfalfa	6.5	6.8	5.3
Other legume forages	6.0	6.8[1]	5.3
Corn	6.0	6.5	5.3
Soybeans	6.0	6.5	5.3
Small grains	6.0	6.5	5.3
Other crops	6.0	6.5	5.3

[1]Birdsfoot trefoil soils should be limed to pH 6.0.

How Lime Works

Even though liming materials are not the same, they all follow the same process to neutralize soil acidity. Lime supplies a surplus of the basic cations Ca^{2+} and/or Mg^{2+} in a carbonated, hydroxide, or oxide form ($CaCO_3$,

$MgCO_3$, CaOH, MgOH, CaO). As the compounds dissolve in soil solution, the carbonate (CO_3^{2-}), hydroxyl (OH^-), or oxide (O^{2-}) react with active acidity (H^+) to form carbonic acid (H_2CO_3) or water (H_2O). Also, because H^+ is being removed from soil solution, free Al^{3+} reacts with OH^- to form an insoluble compound. Hydrogen held by soil-clay (potential acidity) is released into soil solution to maintain chemical equilibrium as active acidity is neutralized, and Al^{3+} is released from the soil to form insoluble compounds. The H^+ released into the soil solution is then neutralized until the CO_3^{2-}, OH^-, and O^{2-} are exhausted. Ultimately, most of the carbonic acid will dissociate to form water and carbon dioxide. Thus, excess H^+ is converted into water, and free Ca^{2+} and/or Mg^{2+} replace the released H^+ and Al^{3+} on the soil exchange sites (Figure 2).

Any legitimate liming material (based on Ohio Department of Agriculture standards (2005) works the same way. However, quality and cost do differ among lime sources.

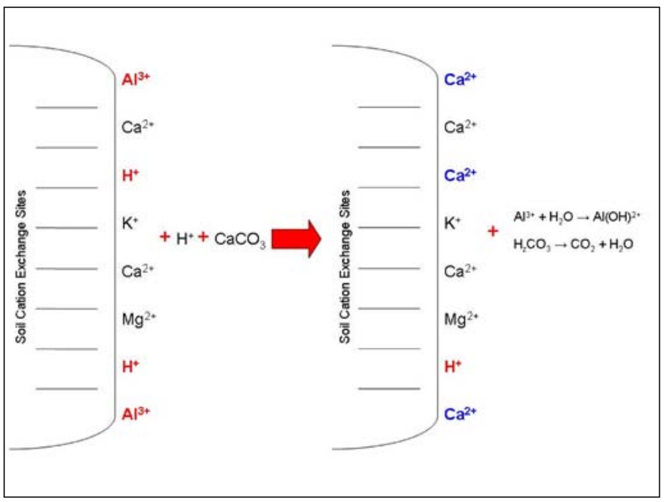

Figure 2. Generalized reaction of typical aglime with soil.

ENP

In Ohio, liming materials are labeled based on their effective neutralizing power (ENP), which is reported in lbs/ton (Table 3). The ENP considers the total neutralizing power (TNP), fineness of grind, and percent moisture of a liming material (Ohio Aglime Council, 2003), and may be calculated by Equation 1.

Equation 1:

ENP (lbs/ton) = TNP/100 * FI/100 * %DW/100 * 2000 lbs/ton

TNP

Total Neutralizing Power (TNP) is a measure of the ability of a liming material to raise the pH. The percentage of calcium, percentage of magnesium, and impurities, such as silt and clay, determine TNP. Pure calcium carbonate has a neutralizing power of 100: other liming materials are compared on a percentage basis with it (Table 3). The two major liming materials are dolomitic and calcitic limestone. Both are sources of calcium and magnesium, but the percentage of each varies and thus the TNP varies.

Dolimitic limestone contains approximately 20 to 22% calcium and 11 to 13% magnesium. Because of molecular weight differences, magnesium carbonate—on a pound for pound basis—is 16% more effective in raising the pH than calcium carbonate. Therefore the TNP will normally range from 100 to 110 for dolomitic limestone. Calcitic or hi-cal lime contains approximately 32 to 35% calcium, 2 to 5% magnesium, and has a TNP of 90 to 99.

Table 3. Total neutralizing power (TNP), fineness, water content, and ENP of common liming materials.

		Fineness					
		% passing mesh size					
Grade	**TNP (%)**	**8**	**20**	**60**	**FI**	**Water (%)**	**ENP (lbs/ton)**
Aglime superfine	100	100	100	100	100	0	2000
Dolomitic hydrated aglime	140	100	99	76	90	0	2520
Calcitic aglime	99	99	60	37	59	0	1168
Dolomitic aglime	105	97	95	90	93	0	1953
Waste water lime	102	100	100	100	100	74	530
Pelletized lime	93	100	100	100	100	0	1860

These are liming materials available in the state of Ohio. Depending upon source, lime characteristics will vary.

Fineness of Grind

Fineness of grind is also considered when determining the ENP of a liming material. Because the neutralization of soil acidity is based upon the dissolution of the lime material in soil solution, the finer the grind, the more effective the material is in neutralizing soil acidity quickly. Fineness of aglime in Ohio is determined by passing a lime material through three different sized screens. The percentage of materials that pass 8, 20, and 60 mesh screens is used to compute a fineness index (FI) (the higher the mesh number, the smaller the lime particle). Liming materials that contain smaller particles neutralize soil acidity faster and more effectively than materials with larger particles when applied at equivalent rates. The fineness index of a liming material is calculated using Equation 2.

Equation 2:

$$FI = (0.2 * (\% \text{ pass } 8 - \% \text{ pass } 20)) + (0.6 * (\% \text{ pass } 20 - \% \text{ pass } 60)) + (1 * \% \text{ pass } 60)$$

Water Content

Water content is also important when determining ENP. Water does not contribute to the neutralization of soil acidity; thus, its presence in liming material only adds to the weight of the material (which is important because liming materials are sold and transported based on weight). Water content may be an issue with by-product limes, such as municipal water treatment sludges, because it may be high if the material is not properly dried and stored before distribution. Based on the water content, a percent dry weight (%DW) can be computed using Equation 3.

Equation 3:

$$\%DW = (100 - \% \text{ water})$$

Even though ENP is the only value needed for selecting lime material, the TNP, fineness of grind, water content, and the percent calcium and magnesium may also be found on the lime analysis sheet for a given material.

Lime Recommendations

Once it has been determined that liming is necessary by soil pH and the buffer pH measurement, a lime recommendation can be made (Table 4). Reported lime rates assume an effective neutralizing power (ENP) of 2000 lb/ton and an incorporation depth of 8 inches. To compute the application rate of a lime source with an ENP different from 2000 lb/ton use Equation 4.

If depth of incorporation is different than 8 inches, divide the lime recommendation by 8 and multiply by the new depth. For example, assume the lime rate needed is 1.6 t/A from Table 4. The lime will be incorporated

Table 4. Tons of liming material (ENP of 2000 lbs/ton) needed to raise the soil pH to the desired pH level based on the SMP (Shoemaker-McLean-Pratt) buffer and an incorporation depth of 8 inches (adapted from Tri-State Fertilizer Recommendations, 1996).

Buffer pH[1]	Desired pH levels				
	Mineral soils			Organic soils	
	6.8[2]	6.5[3]	6.0[4]	Soil pH	5.3
	tons agricultural limestone/acre				tons/acre
6.8	0.9	0.8	0.7	5.2	0.0
6.7	1.6	1.4	1.1	5.1	0.5
6.6	2.2	2.0	1.6	5.0	0.8
6.5	2.9	2.5	2.0	4.9	1.3
6.4	3.6	3.1	2.5	4.8	1.7
6.3	4.2	3.6	3.0	4.7	2.1
6.2	4.9	4.2	3.4	4.6	2.5
6.1	5.6	4.7	3.9	4.5	2.9
6.0	6.2	5.3	4.4	4.4	3.3

[1]To compute LTI multiply buffer pH by 10.
[2]For desired pH of 6.8: lime recommendation = -6.8*buffer pH + 46.8
[3]For desired pH of 6.5: lime recommendation = -5.6*buffer pH + 39.1
[4]For desired pH of 6.0: lime recommendation = -4.6*buffer pH + 31.8

into the top 6 inches, so the new rate of lime is 1.2 t/A, (i.e., 1.6/8 x 6 = 1.2). For no-till fields, assume 4-inch incorporation depths, so rates should be one-half the recommendation given in Table 4.

Lime Selection

Selecting the correct liming material may seem daunting due to the number of products available, but remember that all liming materials react with the soil the same way to neutralize soil acidity. Base your selection of lime material on three things: soil magnesium levels, ENP, and cost of material.

If soil magnesium is low, dolomitic lime sources should be considered. Dolomitic lime contains magnesium and calcium and is considerably less expensive per pound of magnesium than alternative sources of magnesium. Soil test magnesium is considered adequate if soil test levels are greater than 50 ppm (100 lb). Hi-cal (calcitic) lime should be used if the percentage of base saturation of calcium on the soil test is equal to or lower than the percentage of base saturation of magnesium (a Ca:Mg ratio of 1:1 or less), otherwise, economics should guide the selection.

All liming materials sold commercially in Ohio are evaluated by the Department of Agriculture to guarantee their analysis. Every retail outlet that sells a liming material is required by law to have an analysis of the material available (if the lime is bulk, the data sheet should be present on the premises; if the lime is bagged, the bag should have the analysis printed on it). If the analysis is not readily available at the outlet, the retailer should be able to find the analysis online through the Ohio Department of Agriculture web site (http://www.ohioagriculture.gov/pubs/divs/plnt/curr/ff/plnt-ff-limeanalysis-2003.pdf).

The only value needed from the lime analysis sheet is ENP, given as pounds per ton (be careful not to use %ENP, which may also be on a lime analysis report). ENP will allow a producer to determine the amount needed and the cost of each source. To determine the amount of liming material needed, utilize Equation 4.

Equation 4:

$$\text{Tons of material} / A = LR \times \left(2000 / ENP \right)$$

Where LR (ton/A) is the lime requirement based on the Tri-State Fertilizer and lime recommendation. This calculation determines the amount of a specific lime source needed to neutralize acidity to the appropriate pH level.

To determine the cost of a liming material ($/A) use Equation 5. This equation allows for a comparison of liming materials based on cost.

Equation 5:

$$Cost \left(\frac{\$}{A} \right) = \frac{LR}{ENP / 2000} \times \frac{\$}{ton}$$

Example

Let's assume two liming materials are available. Lime source A has an ENP of 900 lb/ton and costs $14/ton; lime source B has an ENP of 1500 lb/ton and costs $20/ton. If the lime requirement is 2.2 ton/A (based on Tri-State recommendations), 4.8 ton/A of lime source A would have to be applied at a cost of $68.44/A. Lime source B would have to be applied at a 2.9 ton/A rate at a cost of $58.60/A. Obviously lime source B is the cheaper of the sources ($9.84/A cheaper), even though lime source A is cheaper on a per ton basis.

If the liming material is purchased directly from a quarry, the cost of hauling must be considered. Let's assume the material is being shipped from a quarry at a cost of $0.50/mile over 100 miles. To factor this cost into the price per acre ($/A), divide the cost of hauling, in this case $50 ($0.50/per mile * 100 miles), by the number of acres to be covered. So if 60 acres are to be covered it costs an additional $0.83/A ($50 hauling charge/60 acres).

Summary

In summary, make sure you obtain a soil test, determine if lime is needed for your crop situation, determine if magnesium is needed, and then use the ENP and magnesium content to select the most cost-effective lime material. Soil testing every three to four years can determine the continuing lime requirements for your fields.

Available online is an Excel spreadsheet to help you determine lime material rates and to compare different lime sources based on ENP and cost. The Excel file can be found and downloaded at: **http://agcrops.osu.edu/fertility/**

REMEMBER: All liming materials react with the soil the same way to neutralize soil acidity. Make your selection based on soil Mg^{2+} level, ENP, and cost.

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