NebGuide

Published by University of Nebraska–Lincoln Extension, Institute of Agriculture and Natural Resources

G1504
Revised June 2015

Lime Use for Soil Acidity Management

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Soil acidity can reduce crop productivity by directly affecting roots and changing the availability of essential nutrients and toxic elements. Liming can neutralize soil acidity, but several factors can affect the economic benefits of liming.

Most field crops perform best at a soil pH between 6.0 and 6.8. This pH range provides the best balance of available nutrients. When soil pH is below this range (*Figure 1*), some nutrients become less available (e.g., phosphorus, molybdenum). Some elements, such as manganese and aluminum, become toxic in highly acid soils (< 5.0). With continuous cropping, soil pH can decrease (i.e., increase in acidity) because of various factors, including crop removal and leaching of basic cations (i.e., calcium and magnesium), application of ammonia-based nitrogen fertilizers, and organic matter decomposition. Adding lime or other materials with liming properties can raise soil pH to the ideal range for crop production, create an environment for a healthy function of microbes, and increase the levels of calcium or magnesium.

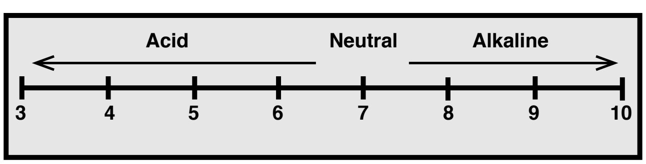


Figure 1. Range of soil pH.

Determining Lime Need

Soil acidity consists of active and reserve acidity. Most of the acid-causing elements (hydrogen and aluminum) are held by the cation exchange sites of the soil particles and organic matter. This is referred to as reserve acidity. Soils with large amounts of clay and organic matter have high potential for reserve acidity. Soil pH is a measure of active acidity, the hydrogen ion concentration in the soil solution. The higher the concentration of hydrogen ions in the soil solution, the lower the pH (i.e., greater acidity). The active acidity is present in the immediate environment of roots and microbes. The total acidity is the sum of the reserve and active acidity. Lime neutralizes both the active acidity and some of the reserve acidity. As active acidity is neutralized by the lime, reserve acidity is released into the soil solution, maintaining the active acidity or the pH. The ability of a soil to resist changes in pH is called buffering capacity and is largely due to the reserve acidity. More lime is required to neutralize acidity on a highly buffered soil compared to a less buffered soil (*Table I*).

Table I. Examples of approximate lime required to raise the pH of soils of different textural classes. (Source: *Nutrient Management for Agronomic Crops in Nebraska*, EC155, UNL Extension.)

Soil Texture	*CEC (meq/100 g)*	*Soil pH*	*Buffer pH*	*Lime rate (tons/acre)*
Loamy sand	6	5.6	6.8	1
Silt loam	14	5.5	6.6	2
Silty clay loam	24	5.6	6.2	4

University of Nebraska lime recommendations are based on raising soil pH to 6.5. When soil pH is less than 6.3, laboratories measure pH in a buffer solution that accounts for both active and reserve acidity. (Refer to NebGuide G1503, *Management Strategies to Reduce the Rate of Soil Acidification* for more details.) Buffer solution is composed of an acid and its salt, and can neutralize both high and low pH soils. The two types of buffer solutions used in Nebraska are the Woodruff and SMP, both at pH 7.0. Soils with a pH of less than 6.3 are added to the buffer solution and the pH of the soil-buffer mix is measured. The more the soil-buffer mix pH decreases below 7.0, the higher the reserve acidity and lime requirement of the soil. The Woodruff and SMP buffer solutions give similar results for most soils; however, the Woodruff buffer is preferred for sandy soils, and the SMP buffer is preferred when the soil is high in exchangeable aluminum.

University of Nebraska lime recommendations are based on liming material that has a 60 percent effective calcium carbonate equivalent (ECCE). Effective calcium carbonate equivalent is further discussed in the *Lime Quality* section. For each 0.1 pH buffer reading below 7.0, application of 1000 to 1200 lb/A of ag-lime (60 percent ECCE) is recommended to raise the soil pH to approximately 6.5 in the top 7 inches.

If lime ECCE is more or less than 60 percent, the rate is adjusted by multiplying the recommended rate by 60 and dividing by the actual ECCE (*Table II*). For example, if the recommended rate is 6,000 lbs (3 tons) per acre and the lime is 45 percent ECCE, then the lime rate is adjusted as:

$$\text{Adjusted lime rate} = \text{Recommended lime rate} \times \text{Adj. factor}$$
$$6000 \text{ lb lime/A} \times 60 / 45 = 8000 \text{ lbs/A}$$
or
$$6000 \text{ lb lime/A} \times 1.3 = 8000 \text{ lbs/A}$$

Lime Quality and Materials

Lime Quality — Two factors determine the effectiveness (ECCE) of liming materials:

1. neutralizing value or purity, also referred to as calcium carbonate equivalent (CCE)
2. particle size or fineness of the liming material.

Table II. Rate adjustment for ECCE different than 60 percent. New application rate is determined by multiplying rate at 60 percent ECCE by the adjustment factor.

ECCE	*Adjustment Factor*
15	4.0
25	2.4
35	1.7
45	1.3
55	1.1
65	0.92
75	0.80
85	0.70
95	0.63

Table III. Calcium carbonate equivalent (CCE) of liming materials.

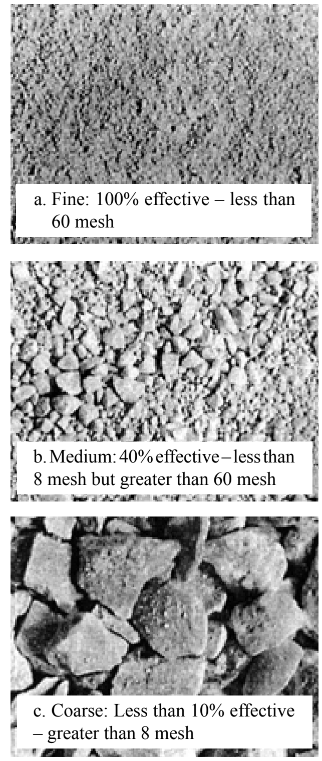
Material	*CCE%**
Pure calcite	100
Calcitic lime	75-100
Dolomitic lime	75-109
Hydrated lime	120-136
Burned lime	179
Pel-lime (finely ground ag-lime)	90-95
Fly ash**	43-44
Wood ash	30-70

* These values only consider the purity of the material, however the fineness also must be considered to determine the effectiveness of the lime (i.e., ECCE = CCE times fineness).

** Based on UNL research on ash from power plants in Nebraska. Fly ash CCE values and other chemical analyses should be done due to variation caused by source of coal, collection procedures and other factors.

The neutralizing value, or CCE, is the amount of acid on a weight basis that a given quantity of lime will neutralize acidity. It is expressed as a percentage of the neutralizing value of pure calcium carbonate or calcite (100 percent CCE). A lime that neutralizes 80 percent as much acid as pure calcium carbonate is said to have a CCE of 80. *Table III* shows the CCE of different liming materials.

Particle fineness is important for lime effectiveness. The neutralization effect is greater with small particles because of increased total surface area exposed to the soil acidity. Lime distribution in the soil also is important because the lime effect of a particle extends only about 1/8 inch. Two sieves, 8 and 60 mesh, are used to separate a sample into three particle sizes (*Figure 2*):



a. Fine: 100% effective – less than 60 mesh

b. Medium: 40% effective – less than 8 mesh but greater than 60 mesh

c. Coarse: Less than 10% effective – greater than 8 mesh

Figure 2. Ag-lime separated by sieving into three size ranges. (Mesh size equals openings per inch, e.g. 8 mesh equals 1/8-inch square sieve openings.

- less than 60 mesh — fine
- less than 8 mesh but greater than 60 mesh — medium
- greater than 8 mesh — coarse

The percentages of these three components are multiplied by factors of 1.0, 0.4, and 0.1 respectively, and added together to give the fineness factor. For example, if a liming material has a particle size distribution of 66 percent fine, 22 percent medium, and 12 percent coarse, the particle fineness of the material is calculated as:

$$\text{Fineness} = (66 \times 1) + (22 \times 0.4) + (12 \times 0.1) = 76 \text{ percent}$$

Effective calcium carbonate equivalent (ECCE) is the measure of the effectiveness of liming materials and is calculated as the product of the purity value (CCE) and the fineness value divided by 100. For example, if the purity is 80 percent and the fineness value is 75 percent, then:

$$\text{ECCE} = (80 \times 75)/100 = 60 \text{ percent}$$

Liming Materials (See *Table III*)

Ground limestone is the most common liming material and consists of calcium carbonate and magnesium carbonate.

Hydrated and burned (quick) limes are quick acting and have high ECCE, but are caustic and difficult to handle.

Pel-lime (granular lime) is finely ground lime material compressed into pellets or granules to reduce dust associated with very fine particle size. The pellets break down in water and the particles quickly disperse and neutralize soil acidity. Application rates are less than with ag-lime because the particles are finer.

Lime slurries, also called fluid lime and liquid lime, are pulverized limestone suspended with 30 to 50 percent water.

Sugar factory lime is very finely ground calcium carbonate used in the production of sugar from beets.

Basic slag or calcium silicate is a byproduct of the steel industry.

Fly ash is a byproduct of coal combustion. The chemical characteristics of fly ash depend on the source of the coal. Some coals have high sulfur content and can produce fly ash with low pH while others have lower sulfur content and have high calcium and magnesium contents.

Lime Application Considerations

Lime Application — Lime takes time to neutralize soil acidity. Often as much as six months may be needed before pH changes significantly. Neutralization will be quicker if particle size is small (less than 60 mesh) and the lime is well mixed with the soil. Typically, it will take two to three years to observe the full effect of ag-lime application on soil pH.

Lime recommendations are usually made to reach a target pH in the top 7 inches of soil. Under no-till systems, lime is surface applied and not mixed with the soil. Mixing eventually will occur because of lime falling into cracks, earthworm activity, soil disturbance with planting and other field operations, and irrigation and/or precipitation moving the lime slowly downward. Surface-applied lime in a no-till system has been found to move downward at about 1/2 inch per year on fine-textured soils. Several years are required to neutralize acidity below a 2-inch depth. Therefore, lime rates should be adjusted to 30 percent of the full rate since only the surface 2 to 3 inches of soil will be reacting with the lime. Periodic soil sampling in the 0-2, 2-4, and 4-8 inch ranges is the most reliable method to determine pH changes and lime requirement over time for no-till systems.

Cropping Systems and pH Threshold

The economic threshold for lime application depends on the most sensitive/responsive crop in the rotation. Soil pH thresholds for profitable response to lime application over a 5- to 10-year period are pH 6.0 for alfalfa-corn-soybean system; 5.6 to 5.8 for corn-soybean system, and 5.0 to 5.2 for continuous corn system. The pH thresholds are for the top 8 inches of soil with the assumption that the subsoil/ subsurface soil pH is 6.0 or greater than 6.0. (Acidification of the 8 to 24 inch subsoil is less common in Nebraska soils.)

Stratification of Soil pH

Soil pH stratification in the surface 8-inch depth should be considered when liming. Stratification of pH occurs especially in no-till sandy soils where anhydrous ammonia has been injected at a 4- to 8-inch depth for many years. At the depth of injection, an acidified layer is created due to hydrogen ions generated during the nitrification process (see NebGuide G1503).

This layer of acidity is difficult to correct under no-till systems because of slow movement of surface-applied lime. A single deep tillage to incorporate lime in the layer of acidity may be needed to alleviate the acidity problem. While there will be an added cost for the tillage operation and the loss of some of the no-till benefits, this may be more than offset by gains in productivity if a very acidic layer has developed. Sampling in layers of 0 to 2, 2 to 4, and 4 to 8 inches will help determine if tillage for lime incorporation is needed.

Site-specific or Variable Rate Application

Lime requirements vary within fields and can be mapped by grid soil sampling, on-the-go sampling and testing of the soil, or by sampling zones within fields. On-the-go sampling and testing may result in 20 to 50 times more samples compared with a two-acre grid sampling approach and does result in more detailed maps. However, broadcast lime application equipment generally does not allow sufficient control over lime placement to take good advantage of the more detailed application maps.

Management or sampling zones may be determined based on past crop and soil management, soil type and topographic position differences, manure application history, and yield differences, such as indicated by yield maps and remote images of the crop. Topographic position can imply differences in lime requirement. For example, for rolling cropland in southeast Nebraska, lime requirement was on average 21 percent more on hilltops and 16 percent less on bottomland, compared with hillsides.

After sampling by grids, on-the-go testing, or sampling zones, the results of the soil analysis need to be considered to determine if there is sufficient variation to justify variable rate or site-specific application.

Economic Considerations

The cost of liming soil to a depth of 6 to 8 inches should be considered an investment of five to 10 years. This is illustrated with an example from Washington County in a disk-tilled system where the initial soil pH was 5.5 and the cost of liming with ag-lime (60 percent ECCE) was $44 per acre (Nebraska Soybean and Feed Grains Profitability Project, Peterson and Hilgenkamp). Over 16 years, the total yield increase was 35 bu/ac for soybeans and 12 bu/ac for corn (*Figure 3*). Assuming soybean and corn prices of $10 and $4 per bushel, respectively, an initial liming cost of $44 per acre, and an interest rate of 5 percent, the average annual income was greater than the average annual expense by year four. In this case, 88 percent of the increase in profit came from increased soybean yield and only 12 percent from increased corn yield.

The economics of lime use on rented land needs special consideration. The increased yield of three or four harvests may be needed to break even on the costs of lime application (*Figure 3*). In some leases, the landowner may need to pay part or all of the cost of liming the field. Some leases stipulate that if a producer loses the lease, the landowner has to repay a portion of the producer's investment in lime. The framework for expected returns of liming will need to be considered when negotiating responsibility for the cost of lime application.

Pel-lime is expected to neutralize acidity sooner than ag-lime

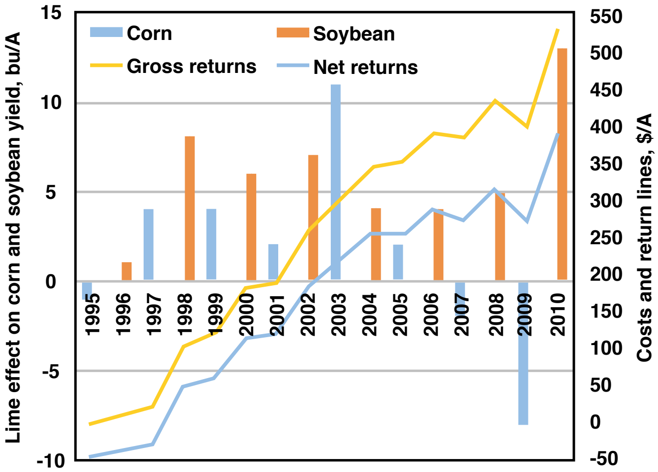


Figure 3. Cumulative lime effect with tillage (initial pH of 5.5; liming cost of $44/ac). (From Nebraska On-farm Research Network, 2014.)

but the long-term effectiveness of the two products in neutralizing acidity depends on their ECCE. Applying 1500 lb/ac of 60 percent ECCE ag-lime eventually will have the same effect on soil acidity as 1000 lb/ac of 90 percent ECCE pel-lime. Pel-lime may have a special role in some situations, such as short-term neutralization of acidity in a band near the roots of soybean to improve nitrogen fixation and yield. Surface application of pel-lime to increase pH at the soil surface may improve the performance of specific herbicides. Cost difference, however, is a major consideration when choosing between pel-lime and ag-lime.

Current recommendations are to apply enough lime to raise soil pH to about 6.5. This is well above the economic threshold for pH-induced yield loss for most Nebraska crops. Applying, for example, less than the recommended rate should be sufficient to maintain soil pH above the economic threshold for more than five years. A second application can be made several years later when soil pH again approaches the threshold level. The economic advantage of split application of lime depends on the reduction in interest cost compared to the cost of split-application. The lime source proximity and transportation costs also must be considered with a split application.

Summary

Several factors need to be considered for profitable lime use:

- Zonation of fields based on differences in management history, soil texture, soil type and topographic position should be considered in sampling for lime requirements.
- Threshold pH levels will differ for various crop rotations.
- Optimal liming practices differ for no-till and tilled conditions.
- It may take five to 10 years after application to recover the cost of liming.
- Product cost relative to ECCE is the major factor when comparing liming materials.
- Split application of a recommended amount of lime, with the second application several years later, may be more economical than applying all at once.

Additional Resources

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