

## Managing Soil pH for Crop Production

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### Summary

- Soil pH is a measure of the relative acidity or alkalinity of the soil solution, and is expressed on a 14-point scale. Soil acidity increases as pH drops below 7 (neutral pH) and soil alkalinity increases as pH increases above 7.
- Soil pH affects many aspects of crop production, including nutrient availability, potential for metal toxicity, efficacy and degradation of soil-applied herbicides, and nitrogen fixation by leguminous crops.
- Soil pH should be maintained in a neutral to slightly acidic range (6.0 to 7.0) for grain crops, but closer to neutral (6.8 to 7.0) for forage legumes, which are more sensitive to aluminum toxicity in acidic soils.
- Regular lime applications are required in most areas to prevent soils from becoming acidic over time due to natural processes and fertilizer inputs.
- Lime application rates are determined based on soil type, lime quality and tillage depth. Consult local extension recommendations or your crop consultant for region-specific guidelines for determining lime application rates.

### What is Soil pH?

The term pH stands for the potential (p) of hydrogen ions ( $H^+$ ) in water, and provides a measure of the relative acidity or alkalinity of the soil solution. Soil pH is expressed on a 14-point scale, where a value of 7.0 is considered neutral. Lower values on the pH scale denote increasing  $H^+$  ions and acidity, while higher values represent increasing hydroxyl ( $OH^-$ ) ions and alkalinity. Because pH is expressed on a logarithmic scale, each change of one pH unit actually represents a 10-fold increase in soil acidity or alkalinity.

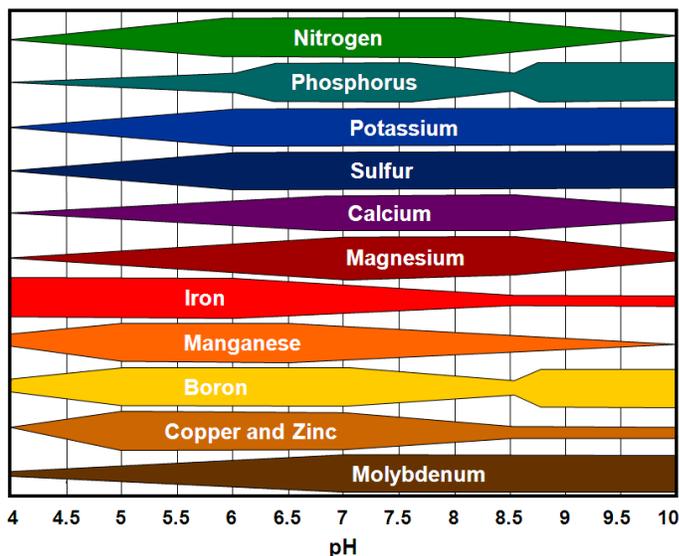
### Sources of Soil Acidity

Many soils have a tendency to become acidic over time. Soil acidity increases as a result of: (1) weathering of soil minerals and release of acidifying aluminum ( $Al^{3+}$ ) ions; (2) rainwater leaching away base ions such as calcium ( $Ca^{2+}$ ), magnesium ( $Mg^{2+}$ ), potassium ( $K^+$ ) and sodium ( $Na^+$ ); (3) decomposition of soil organic matter and generation of organic acids; (4) plant roots releasing  $H^+$  ions and organic acids as they grow; and (5) application of ammonia-based fertilizers, which release  $H^+$  ions when converted to nitrate by soil bacteria. Nitrification of ammonia fertilizers, organic matter decomposition and base ion leaching are generally the leading sources of soil acidity in the eastern US.

### Importance of Soil pH for Crop Production

Soil pH affects many physical, chemical, and biological reactions necessary for crop survival, growth and yield.

**Nutrient Availability** is strongly influenced by pH, and is probably the second most important reason for soil pH management. The relationship between soil pH and nutrient availability is shown in Figure 1.



**Figure 1.** Relative availability of crop nutrients by soil pH.

Generally, macronutrients including nitrogen (N), potassium (K), sulfur (S), calcium (Ca) and magnesium (Mg) are most available in slightly acidic to moderately alkaline soils, while the availability of micronutrients such as iron (Fe), manganese (Mn), boron (B), copper (Cu) and zinc (Zn), is increased in moderately acidic soils. There are several exceptions to these generalizations, however.

In contrast to other macronutrients, phosphorus (P) availability is restricted to a fairly narrow, neutral pH range. Below a pH of 6.5, P becomes unavailable as it forms insoluble compounds with Fe and Al. Conversely, above a pH of 7.5, P becomes unavailable as it forms insoluble compounds with Ca and Mg. Molybdenum (Mo) availability also deviates from general micronutrient trends, as it is most available in alkaline soils. Finally, for some nutrients, availability can depend on other soil factors in addition to pH. For example, Mg deficiency in corn (Figure 2) is most common on sandy and low organic matter soils that have both low pH and low cation exchange capacity (CEC).



**Figure 2.** Magnesium deficiency in corn, which often occurs on sandy and low organic matter soils that have both low pH and low cation exchange capacity (CEC).

**Metal Toxicity** negatively effects root growth in acidic soils, and is the most important reason for managing soil pH. Certain metals such as Fe, Al and Mn are released into the soil solution when pH becomes acidic. These metals, particularly Al, damage plant roots by interfering with cell division and cell wall formation, and also interfere with the uptake, transport and use of nutrients, including Ca and P. Aluminum is not a plant nutrient, and is not actively taken up by crops, but can enter plant roots passively through osmosis when it is present in the soil solution. Alfalfa and other forage legumes are especially sensitive to Al toxicity in acidic soils.



**Figure 3.** Poor alfalfa growth in field areas due to low soil pH.

**Efficacy and Carry-over of Soil-Applied Herbicides** can also be affected by soil pH. In general, herbicides will be bound to the soil when herbicide and soil pH are similar. When herbicides are bound to the soil, weed control efficacy and herbicide degradation rate are both reduced. For example, triazine herbicides are acidic, and will be bound when applied to low pH soils. In such a situation, weed control in corn treated with atrazine would be reduced and the potential for injury to a following soybean crop increased. In this scenario, applying lime immediately prior to soybean would exacerbate the potential for crop injury, as soil-bound herbicide is

released from the soil in response to increased pH. While triazine herbicides are bound in acidic soils, some herbicides (e.g., sulfonyleureas) are bound in high pH soils and others (e.g., pendimethalin and metolachlor) are unaffected by soil pH. Consult individual herbicide labels for specific information regarding pH responses. The best way to avoid pH-related problems with soil-applied herbicides is to maintain soil pH consistently in the neutral range.

**Nutrient Transformations and Nitrogen Fixation** are restricted in acidic soils, due to reduced activity of the microorganisms that are responsible for these processes. Plant available forms of N, S and P are all reduced in acidic soils, as is symbiotic N fixation by leguminous crops.

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## Soil pH Management Targets

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Optimum pH level varies by cropping system. For grain crops and forage grasses, pH should generally be maintained between 6.0 and 7.0. For cropping systems that include alfalfa, clover and other forage legumes, it is recommended that a less acidic pH of 6.8 to 7.0 be maintained, due to particular sensitivity of these crops to Al toxicity in even slightly acidic soils.

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## Monitoring Soil pH

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Regular soil sampling and testing are the keys to effective soil pH management. Soil samples should be collected every 2 to 4 years for a given field and at the same time every year so that analyses are comparable over time. Sampling 3 to 6 months prior to the next crop will allow enough time for any required pH adjustments to begin to take effect. For many crops, the best time to sample is following harvest in late autumn. See the previous *Crop Insights* on [Soil Sampling and Test Interpretation](#) for a thorough overview of soil sampling techniques (Diedrick, 2011). While various pH meters and dye-based test kits are commercially available, they are not a replacement for professional testing and laboratory analysis, due to the risk of high variability and questionable precision. A good laboratory test report is a small investment compared to the cost of lost yield or unnecessary lime applications.

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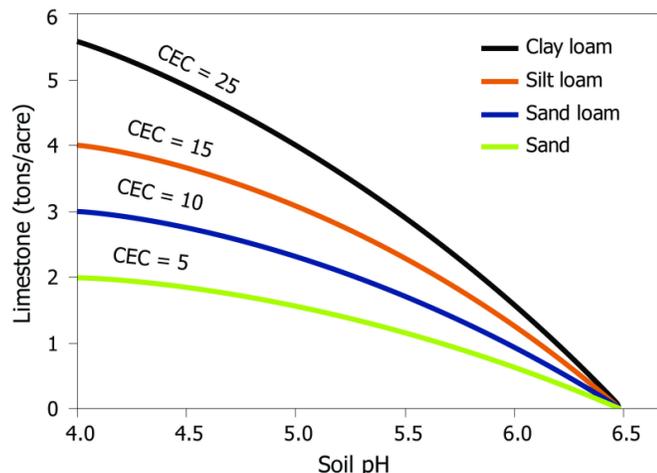
## Liming to Increase Soil pH

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While excessively high soil pH can negatively impact crop production, the costs associated with reducing soil pH - through application of elemental sulfur or other acidifying materials - are rarely justified for grain and forage crop production. On the other hand, liming to increase the pH of acidic soils is economically advantageous when proper management guidelines are followed. For a given initial soil pH and cropping system pH target, liming rates to increase soil pH are determined based on three primary factors: soil type, lime quality, and tillage depth.

**Soil Type** determines the amount of lime that is required to change pH. Total soil acidity is the sum of active acidity and buffer or reserve acidity. Most of the acid-causing,  $H^+$  and

Al<sup>3+</sup> ions in the soil are held on the cation exchange sites of soil particles and organic matter. For this reason, soils containing large amounts of clay and organic matter will have a high buffering capacity and require larger amounts of lime to increase soil pH than sandy and low organic matter soils that have a lower buffering capacity (Figure 4).



**Figure 4.** Approximate amount of limestone required to increase pH of upper seven inches of soil to 6.5 for four soils with differing CECs. Adapted from Halvin et al., 1999.

**Lime Quality** determines the efficiency with which a given liming material changes soil pH. Lime quality is the outcome of two factors:

1. The neutralizing value of the liming material, referred to as calcium carbonate equivalent (CCE)
2. The fineness of the liming material

Calcium carbonate equivalent represents the amount of acid that a given quantity of a liming material will neutralize when fully dissolved, relative to pure calcium carbonate (CaCO<sub>3</sub>). For example, a liming material that neutralizes 85% as much acid as pure CaCO<sub>3</sub> would have a CCE of 85. The CCE of several common liming materials is presented in Table 1.

The fineness of a liming material determines how quickly it will dissolve after application, and therefore, how rapidly it will react with the soil to increase pH. Liming materials with a smaller particle size will neutralize soil acidity more quickly than materials with similar CCE, but larger particle size. Lime fineness is determined by manufacturers via a process where the material is passed through sequentially sized sieves. Lime fineness is generally expressed in terms of three resulting particle size classes (Table 2). In practice, most liming materials are composed of a mixture of particle size classes. Typical ground limestone is composed of approximately 30% fine particles (< 60 mesh), 60% medium particles (> 60 mesh, < 8 mesh), and 10% coarse particles (> 8 mesh).

**Tillage Depth** influences the quantity of lime required to increase soil pH and can also effect the time required for pH to increase. Greater quantities of lime are generally required to increase soil pH as tillage depth increases, because a

greater volume of soil is effectively being treated. Most lime application recommendations are based on a 6- to 8-inch tillage depth, with incremental lime additions or reductions advised, with increasing or decreasing tillage depth, respectively. For no-till systems, lime recommendations are not significantly reduced relative to shallow tillage, but lime will often take longer to take effect.

**Table 1.** Common liming materials and their typical calcium carbonate equivalency (CCE) values (Halvin et al. 1999).

Liming Material CCE	Description
Calcite Lime 80 - 100%	CaCO <sub>3</sub> – Ground limestone is the most commonly available liming material.
Dolomite Lime 95 -110%	CaMg(CO <sub>3</sub> ) <sub>2</sub> – A common ground limestone material containing both Mg and Ca
Burned Lime 179%	CaO – A caustic white powder created when CaCO <sub>3</sub> is burnt. The most effective of all liming materials, but dangerous to handle.
Hydrated Lime 136%	Ca(OH) <sub>2</sub> – a fine white powder created when CaCO <sub>3</sub> is mixed with water and dried. Also called slaked or slack lime. An effective liming material, but difficult to handle.
Slag Lime 60 - 90%	CaSiO <sub>3</sub> – A byproduct of the steel industry. Can also contain Mg and P depending on the source of Fe ore used to make steel.
Pellet / Fluid Lime Varies	Finely ground limestone that has been formed into pellets or suspended in water to improve ease of handling and reaction speed. Has the same CCE as limestone base
Fly Ash Varies	CaO + SiO <sub>2</sub> – A byproduct of coal combustion with highly variable CCE. May contain other metallic constituents, depending on source.

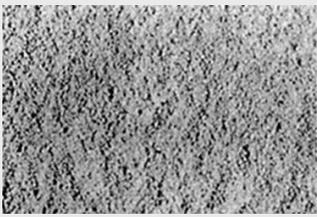
### Determining Lime Application Rate

Methods for determining lime application rates vary regionally, but all recommendations are based on similar underlying principles. Most state extension services provide a table or method to determine the base lime rate required to raise the soil pH from its current level to a crop-specific target value - usually in the range of 6.0 -7.0. This base rate is largely a function of soil type, and is modified by the quality of the lime to be applied and tillage depth. Many recommendations provide methods for combining the CCE and fineness of a

liming material to calculate a single measure of lime quality. For example, [University of Nebraska Extension's lime rate recommendations](#) are based on the effective calcium carbonate equivalent (ECCE) of the intended liming material, which is calculated as the product of the material's CCE and fineness, divided by 100. [University of Illinois Extension's lime recommendations](#) are based on a similar lime quality metric, called effective neutralizing value (ENV). Most recommendations also provide rate modifications for applying lime with varying tillage methods. For example, [Iowa State University Extension's lime rate recommendations](#) provide specific application rates for four different tillage depths, including no-till.

Consult local university extension recommendations for region-specific guidelines for determining lime application rates.

**Table 2.** Ground limestone separated into three size classes. Adapted from Mamo et al., 2009 (including images).

	<p><b>Fine Limestone</b></p> <p>Less than 60 mesh size</p> <p>100% effective one year after application</p>
	<p><b>Medium Limestone</b></p> <p>Less than 8 mesh size, but greater than 60 mesh size</p> <p>40% effective one year after application</p>
	<p><b>Coarse Limestone</b></p> <p>Greater than 8 mesh size</p> <p>10% effective one year after application</p>

### Lime Application Considerations

- Unless using very fine or liquid lime materials, time application to allow at least six months for soil acidity to begin to be neutralized. Fall lime application is recommended in most areas because it also reduces opportunities for compaction and interference with spring planting.
- Lime applications as high as 6 tons/acre can be applied at one time. If a higher rate is required, consider applying 2/3 the recommended rate the first year and the remaining 1/3 3 to 4 years later.
- Soil pH stratification can occur in no-till, pasture and hay fields. In these systems, it is recommended to use lower

individual application rates, but to apply more frequently. This will avoid creation of a high pH surface zone and ensure that lime is readily available to move to and neutralize acidity in lower soil layers. Acidic subsurface conditions are common in sandy, no-till fields and can be quickly alleviated with a single deep-tillage pass.

- Variable-rate lime application is generally considered one of the most economically attractive precision farming practices. In most areas, pH varies across fields due to variation in management history and topography. In many fields, higher lime application rates are required on hilltops than on hillsides and bottomlands. Collect grid or zone samples or use on-the-go sensing to determine if sufficient spatial variability is present to warrant variable-rate application. Precision soil samples will also serve as the basis for the variable-rate application map.



**Figure 5.** Lime application on corn stubble. Image courtesy of Douglas Beegle, Penn State University.

### References

- Halvin, J.L., J.D. Beaton, S.T. Tisdale and W.L. Nelson. 1999. *Soil Fertility and Fertilizers* 6<sup>th</sup> Ed. Prentice Hall. Upper Saddle River, NJ.
- Mamo, M., C.S. Wortmann, and C.A. Shapiro. 2009. Lime use for soil acidity management. Extension Bulletin G1504. University of Nebraska, Lincoln, NE. Available online at: <http://ianrpubs.unl.edu/e-public/live/g1504/build/g1504.pdf>
- Sawyer, J.E., A.P. Mallarino, R. Killorn, and S.K. Barnhart. 2011. A general guide for crop nutrient and limestone recommendations in Iowa. Extension Bulletin PM 1688. Iowa State University, Ames, IA. Available online at: <http://www.extension.iastate.edu/Publications/PM1688.pdf>
- Fernández, F.G., R.G. Hoefl. 2012. Managing soil pH and crop nutrients. p 91-112, in E. Nafziger (ed.), *Illinois Agronomy Handbook*. Available online at: <http://extension.cropsci.illinois.edu/handbook/pdfs/chapter08.pdf>