

SOIL pH AND LIMING

When crops do not grow well, one of the first questions an agronomist is likely to ask is "What is the pH of the soil?" The reason for this question is that soil pH tells us more about a soil's ability to produce crops than any other single measurement. A measurement of soil pH is like a doctor's measurement of a patient's temperature. It gives an indication something may or may not be wrong, but it does not tell the exact nature of the trouble.

What Is Soil pH?

The term pH defines the relative acidity or alkalinity of a substance. The pH can vary from a minimum value of zero to a maximum of 14. The midpoint of 7.0 is considered *neutral* while values below 7.0 are *acid* and values above 7.0 are *alkaline*. The pH of most productive soils ranges from about 5.0 to 8.4.

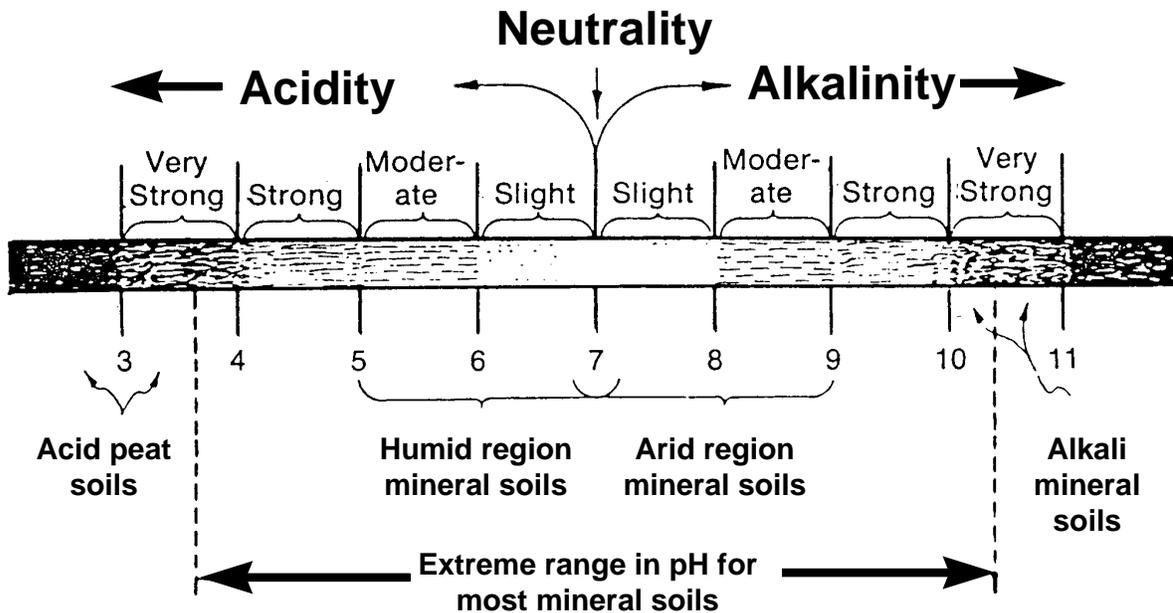
Soil pH is a measure of the H^+ concentration of the soil solution. Hydrogen ions result from the separation of water molecules (H_2O) into H^+ and

OH^- ions. In acid soils H^+ outnumber OH^- ions, in neutral soils H^+ and OH^- exist in equal concentrations, and in alkaline soils OH^- ions predominate.

The actual concentration of H^+ is very small and difficult to express in conventional mathematical terms. For example, the H^+ concentration at neutrality is 0.0000001 or 1/million.

A more convenient form of expressing this number is 1×10^{-7} or pH 7.0. The term pH is a mathematical notation for the negative logarithm of the hydrogen ion concentration. As you might guess, the H in pH stands for hydrogen.

This makes each unit change in pH a ten fold change in acidity-alkalinity. A pH of 4 is 10 times more acid than a pH of 5 and 100 times more acid than a pH of 6 and a 1000 times more acid than a pH of 7. Even a relatively small drop in pH from 6.0 to 5.7 results in a doubling in acidity.



pH	H+ Concentration (Molarity)		
5.0	.00001	or	10 ⁻⁵
6.0	.000001	or	10 ⁻⁶
7.0	.0000001	or	10 ⁻⁷
8.0	.00000001	or	10 ⁻⁸

Importance of Soil pH

Soil pH affects several soil chemical reactions that influence plant growth, nutrient availability, the effectiveness of fertilizers, and the performance of soil-applied pesticides. Several direct and indirect effects on plant growth and nutrition are:

- At low soil pH's, Al and Mn dissolve in amounts that are toxic to plants. When pH is above about 5.5, Al in soils remains in a solid form and is not harmful to plants. The amount of dissolved Al is 1000 times greater at pH 4.5 than at 5.5. Thus, a small change in pH below 5.0 can suddenly cause crop stunting. When Al ion concentrations reach toxic levels, roots deteriorate and appear pruned off. Some sandy soils do not contain as much Al and crops can tolerate an acid pH. Metallic ions such as aluminum, iron and manganese also react with phosphorus in acid soils to form phosphate compounds that are relatively unavailable to plant roots.

Table 1. Effect of aglime rate on hard red winter wheat yields, pH and KCl-extractable Al 4 years after application in Kingman County.

Lime Rate	Four-year Average Yield	0-6" pH	KCl-Extractable Al
lb ECC/a	bu/a		ppm
0	15	4.6	102
3,000	39	5.1	26
6,000	38	5.9	0
12,000	36	6.4	0

Initial pH—4.7, Lime Requirement—12,000 lb ECC/a, KCl-Extractable Al—94 ppm
 Source: Unruh, et. al., KS Fert. Res. Report of Prog., 1986 thru 1989

- At higher soil pH values, the availability of some nutrients decreases. Phosphorus quickly reverts to less soluble calcium phosphate compounds. The availability of several micronutrients also decreases in high pH soils.
- Soil pH affects the population and activity of soil microorganisms. These organisms decompose organic matter, releasing N, P, S and several micronutrients. The activity of organisms causing plant disease or herbicide breakdown may also be altered by pH change. In general, fungi are more active in acid soils and bacteria are more active in neutral or alkaline soils.
- The activity of symbiotic bacteria associated with legume nodules is impaired in acid soils resulting in reduced N fixation by legumes.
- In acid soils there is less Ca and Mg available for plants. Magnesium deficiencies can occur, but calcium deficiencies are very rare.
- The performance and carryover of herbicides including products in the triazine, sulfonylurea, imidazolinone families can be affected by soil pH.

Cause of Soil Acidity:

Some soils are naturally acidic because of the composition of the parent material from which they form and/or the ecosystem in which they were formed. Rocks from which parent material originally formed vary from acidic to alkaline in reaction. Soils formed from granite, are more acidic than soils developed from sandstone or shale. Soils formed from limestone tend to have alkaline pH. Soils formed under forests tend to be more acidic than those developed under grassland. Conifers tend to cause greater acidity than deciduous trees.

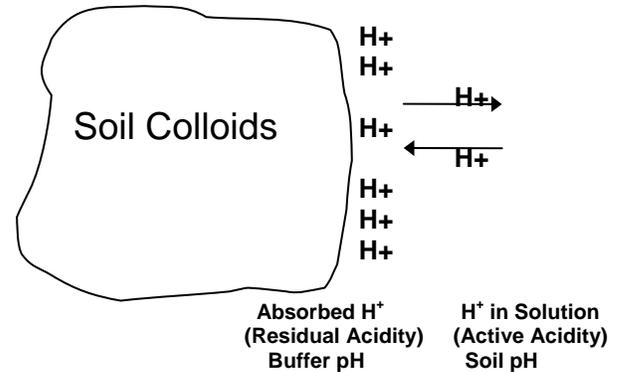
The majority of acid soils, however, are the result of a combination of natural and management related processes. These processes include:

Leaching As water moves through the soil profile, a slow but persistent acidifying effect occurs from downward movement of cations (bases) with the water. This is a very slow acidifying process that takes hundreds of years to have a significant pH change. Obviously, the impact would be greater in the higher rainfall areas compared to drier climates with little leaching. This long-term effect in the United States can be visualized as you think about more acid soils existing in the east compared to the west. Acid rainfall also can contribute to the acidification effect, but the concentration of acid in acid rainfall is relatively low and on a short-term basis is not a major impact on the soil pH.

Crop removal. Calcium, magnesium and potassium (bases) taken up by plants and subsequently removed through harvest can have an acidifying effect on the soil. Removal varies with crop and method of the crop harvest. Removal is greatest for high yielding forages.

Microbial activity. Microbial decomposition of organic and inorganic compounds that either naturally exist or are added to the soil is probably the leading cause of soil acidification. The oxidation of elemental sulfur to sulfate-sulfur is one example of an inorganic reaction. Crop residue decomposition by microorganisms produce a number of weak organic acids that tend to lower soil pH.

contributes to the acidifying effect. Urea, ammonium nitrate, anhydrous ammonia and UAN solutions are all equal in residual acidity formation per pound of N applied. Ammonium sulfate is much more residually acidic on an applied N basis.

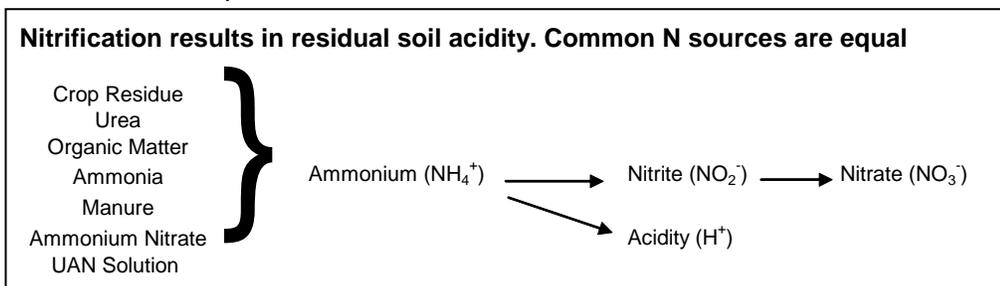


Correction of Soil Acidity

Acid soils contain relatively high concentrations of hydrogen ions compared to alkaline cations such as calcium and magnesium. Soil acidity is corrected by adding a liming material to decrease the concentration of hydrogen ions and increase the level of alkaline or basic cations.

Acid-producing hydrogen ions are adsorbed on exchange sites or present in water films around soil colloids. These hydrogen ions are in constant equilibrium between the adsorbed and solution states. The concentration of H^+ ions in solution is very small relative to the H^+ adsorbed on clay and organic matter. In fact, it has been estimated that it would require less than a pound

of lime to neutralize the H^+ ions in solution in a typical loam soil. The same soil might require several tons of lime to increase its pH to a desired level.



Soil bacteria convert ammonium (NH_4^+) to nitrate (NO_3^-) through a biochemical process called nitrification and H^+ is released resulting in soil acidification. The nitrification reaction occurs on ammonium coming from both organic (crop residue and manure) and inorganic (fertilizer) sources. Nutrient additions, therefore,

The concentration of H^+ ions in solution, though small, is very important and referred to as active acidity. Active acidity is measured by a soil pH test and is the acidity that influences the various chemical and biological reactions in the soil. A soil pH test is sometimes called a water pH.

The H⁺ adsorbed to the cation exchange sites serves as a large reservoir of *potential* or *residual acidity* that rapidly replaces H⁺ ions in solution as they are neutralized by lime. Thus, in order to determine how much lime is required to raise the pH, an estimate of the amount of residual acidity is needed.

A few labs use texture and organic matter in conjunction with soil pH for lime recommendations. However, most labs use a chemical test using a buffer solution to determine the amount of effective calcium carbonate (ECC) necessary to raise the soil pH to a desired level.

Once a soil pH test establishes that a soil is acid and requires lime, a second test called buffer pH or buffer index is performed to estimate the total residual acidity. Buffer means resistance to change. Two acid soils with the same pH may

How Lime Neutralizes Acidity

As indicated previously, lime reduces soil acidity by reducing the concentration of H⁺ and Al⁺⁺⁺ ions and increasing the concentration of non-acidic cations such as Ca⁺⁺ and Mg⁺⁺. The following illustration shows how calcium from lime replaces H⁺ ions on the soil. Al⁺⁺⁺ ions are also precipitated as Al₂O₃.

Not all materials which contain calcium raise soil pH. Effective liming materials must not only contain alkaline cations but they must also contain a negatively charged anion which will combine with and neutralize the H⁺ ions as they are displaced from the exchange sites. Carbonate is an example of an anion which combines with and neutralizes H⁺ while sulfate is one that does not. Calcium sulfate (gypsum) combines with H⁺ to produce sulfuric acid. Gypsum, therefore, is not a liming material.



have very different amounts of potential acidity, exchangeable Ca and Mg and consequently different lime requirements. In general, lime requirement at a given soil pH increases with the level of clay and organic matter in a soil.

A soil pH test tells us if the soil solution is too acidic and requires liming. The buffer pH estimates the amount of total acidity present, and consequently, how much lime is required. The amount of lime required to achieve a desired pH also depends in the depth of incorporation or soil neutralization. Most recommendations are based on neutralization of two million pounds of soil (a soil depth of about 6-7 inches for medium textured soils). If the lime is incorporated deeper, then more lime will be needed. Conversely, if lime is incorporated shallower, then less lime will be needed.

Liming Materials

The Kansas Agricultural Liming Materials Act defines agricultural liming materials as products whose calcium and magnesium compounds are capable of neutralizing soil acidity. This definition allows materials in addition to limestone (CaCO₃) to be considered as lime sources. Liming sources do not include gypsum (CaSO₄) because it is a neutral salt that will not directly change soil pH.

The calcium carbonate equivalence (CCE) of a liming material is defined as the acid-neutralizing capacity expressed as the percent by weight relative to pure calcium carbonate (CaCO₃). Pure calcium carbonate has a CCE of 100.

Calcium carbonate or a mixture of calcium and magnesium carbonate (dolomitic lime) are the most common liming materials used in agriculture because they are relatively plentiful and low in cost. Other common ag lime materials and their relative neutralizing value compared to calcium carbonate are listed in the accompanying information.

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Table 5. Common liming sources, their composition and calcium carbonate equivalence

Liming Material	Composition	Typical CCE (%)
Limestone (calcitic)	CaCO ₃	80-100
Dolomitic lime	CaCO ₃ •MgCO ₃	80-100
Marl	soft CaCO ₃ with clay & organic matter impurities	70-90
Burnt lime	CaO	150-179
Hydrated (slaked) lime	Ca(OH) ₂	120-136
Municipal & industrial lime wastes	CaCO ₃ with impurities	80-100

The effective neutralizing capacity of a liming material depends on factors such as:

Particle Size: The effectiveness of a liming material in correcting soil acidity depends not only on the purity, but also the fineness of material. The fineness of grind is of great importance for calcium and/or magnesium carbonate materials because carbonate materials have a very low solubility in water. The greater surface area associated with finely ground material will speed up their dissolution and reaction. Considerable research has been done on particle size effect on soil acidity neutralization and based on this research effectiveness rating for various particle size ranges have been set and is termed a fineness factor.

Common ag lime is a mixture of fine- and coarse-sized particles. Finely ground particles react much faster than coarse particles since calcium carbonate is relatively insoluble and slow to dissolve. High-quality ag lime has a relatively high proportion of finely ground particles.

Lime Purity: Most ag lime contains a certain percentage of clay, sand, and other impurities that do not neutralize hydrogen ions.

The effective neutralizing value of lime as determined by particle size and purity is expressed as the effective calcium carbonate (ECC) value of the liming material. Common ag

lime materials can range from less than 50% to close to 100% ECC.

As an example, a lime source with a purity factor of 90% and a fineness factor of 80% would have an ECC value of 72% (90% x 80%). When comparing the cost of various sources of ag lime, a farmer needs to base his evaluation on ECC value as well as cost per ton of material.

Fluid lime is a very finely ground calcium carbonate suspended in water. The product typically contains about 40-50% water and 50-60% finely ground calcium carbonate. The finely ground calcium generally originates from municipal water treatment plants. It is used where low rates of lime are required and fluid application is desirable. The main advantages include a more uniform spread and quicker reaction since it contains very fine particle size. Its principal limitations are its higher cost per pound of ECC and its practical rate limit of about one ton per application. There is no "magic" in fluid lime; for the same amount of ECC applied, the total amount of soil acidity neutralized will be the same, regardless of whether dry or fluid lime is used.

Pelletized Lime Pelletized lime (granular) is prepared by adding a binding agent to finely ground ag-lime to obtain a granular material that can be applied with dry granular fertilizer equipment. Pelletizing the lime cuts down the dust and perhaps allows a more uniform spread. It is a convenient source for blending with dry fertilizer and is well suited for use with

Table 7. Effect of rate and source of lime on soil acidity neutralization 8 months after application.

Source	Depth, inch	ECC Rate (lb/a)			
		0	1,250	2,500	5,000
----- pH -----					
Aglime	0-3	5.1	6.0	6.6	6.8
	3-6	4.9	5.2	5.5	5.8
Fluid	0-3	—	6.4	6.5	7.2
	3-6	—	5.2	5.5	5.8

Lime applied in mid-July and incorporated by one disking and field cultivating.

pneumatic (air) applicators. Since the granules are composed of fine sized particles it also reacts relatively quickly in the soil. The final effect on soil pH is determined by its ECC value as are all other lime sources. The pelletizing process, however, does add to the cost of the material. It does not increase its effectiveness when compared to ag-lime at an equal rate of ECC.

When selecting a lime source, the producer needs to remember that the materials are equal in their final neutralization of soil acidity when applied at the same rate of ECC. Thus, cost per unit of ECC applied should be a major consideration in selecting a source. Other factors such as uniformity of spread and speed of reaction (on very acidic soils) should also be considered.

Lime Application

Since lime is relatively insoluble, it is advisable to mix lime uniformly in the soil with tillage implements. For perennial crops, mixing can only be done before seeding. It is advisable to apply the lime as far ahead of the crop as possible to allow time for the lime to react. If the soil is only slightly acidic or the crop is not very sensitive to acidity, liming just before planting may be effective. However, for crops less tolerant of acidity, such as alfalfa, lime application is recommended a year prior to seeding.

Liming recommendations normally are based on an incorporation depth of 6" to 7" through the rotation. If deeper incorporation is performed,

additional limestone is required in direct proportion to the depth. For shallower incorporation, lime application rates should be reduced accordingly.

For no-till systems, perennial forages and cool season grass, assume an effective liming depth of two inches. Since liming materials are only slightly soluble, surface applications will not be moved much deeper in the soil.

Table 4. Adjustment factor for aglime rate for incorporation depth.

Incorporation Depth (inch)	Adjustment Factor
3	.43
5	.71
7	1.00
9	1.29
11	1.57