

# Basic Concepts of Soil Acidity and Liming

**David B. Mengel, Professor Emeritus**  
Kansas State University, Manhattan, KS  
dmengel@ksu.edu

## ABSTRACT

With today's cropping systems utilizing high rates of N fertilizers, most Midwestern soils require periodic applications of aglime or other liming materials for optimum crop production. Liming has several beneficial effects: 1) it reduces aluminum or manganese toxicity, harmful or potentially toxic conditions which can develop in acid soils; 2) it increases the availability of some of the essential nutrients; 3) it replaces the supply of calcium and magnesium essential for plant growth which is depleted as soils become acid; 4) it ensures favorable conditions for the activity of certain herbicides; and 5) it provides a suitable environment for microbial activity.

## WHAT IS SOIL ACIDITY?

By definition, an acid is a proton or a hydrogen donor, while a base is a proton acceptor. In soils, that means that when a large portion of the cation exchange capacity (CEC) is satisfied by acids such as hydrogen ( $H^+$ ) or aluminum ( $Al^{+3}$ ), the soil is acidic and is donating acidity (hydrogen) to the water which surrounds the soil particles. When the CEC is satisfied primarily by basic cations such as calcium, magnesium and potassium, the soil is basic, and it will accept hydrogen from the soil water and donate a basic cation in its place. This ability of soils to accept or donate acidity to the soil solution, depending on the ions which are occupying the charged CEC, results in a stability in soil pH, or buffering.

The ion concentration in the soil water is a reflection of the cations which are held on the soils CEC. In soils that have a large proportion of the CEC satisfied by basic cations, a high base saturation, the concentration of basic cations (calcium, magnesium and potassium) in the water will be high, while the concentrations of acids in the soil water will be low. In soils where the CEC is primarily saturated by acidity (hydrogen and/or aluminum), low base saturation, the concentration of acidity in the soil water will be high and the concentration of bases in the water will be low. Thus the relative concentration of acids and bases on the exchange sites of the soil is what determines the relative acidity found in the soil water.

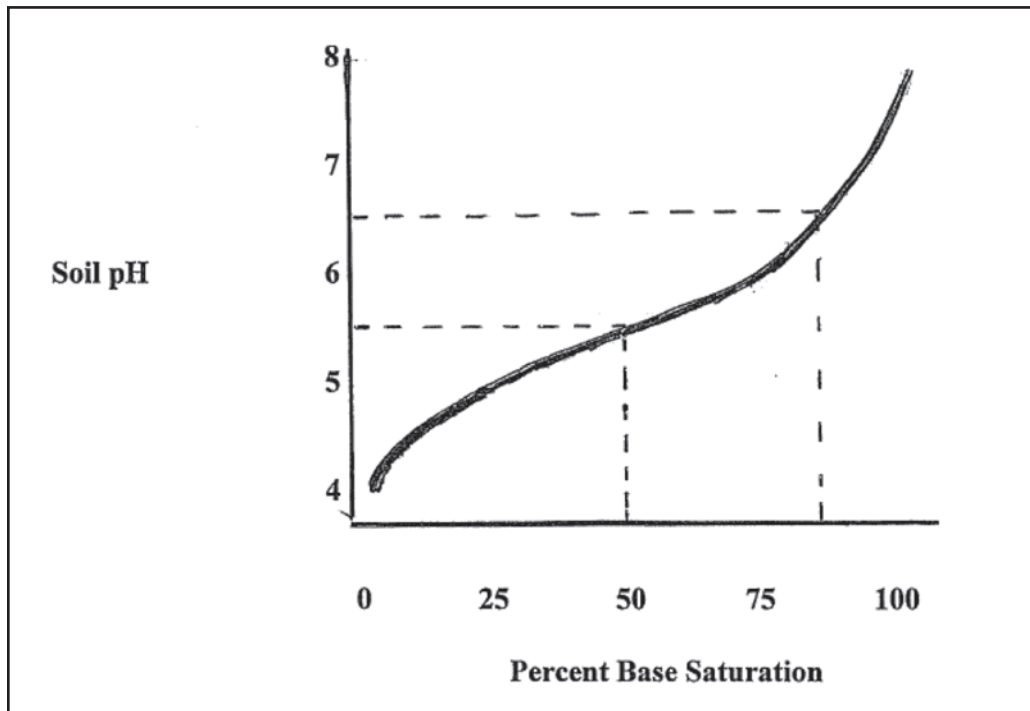
## HOW ACIDITY IS EXPRESSED

The concentration of acidity in a solution is commonly expressed using pH, the negative log of the hydrogen ion concentration (activity) in solution. The pH scale runs from 1 (very acid) to 14 (very basic). The midpoint, pH 7 is neutral, with the concentration of acids in solution being equal to the concentration of bases.

The relative acidity of a soil is commonly measured by estimating the pH, or hydrogen ion activity/concentration in the soil water. This is normally done by collecting a soil sample, mixing

the soil with a standard volume of water and measuring the pH of the soil:water mixture with a pH meter. The pH value obtained reflects both the chemical environment in the soil water where plant roots reside, and also the relative mixture of acids and bases on the soil cation exchange capacity, since the ions in the soil water are in equilibrium with the ions on the exchange sites. Thus altering the soil pH requires changing the balance of acids and bases in both the soil water and on the cation exchange capacity of the soil.

Figure 1 gives a generalized graphical representation of the relationship between percent base saturation and soil pH commonly found in the Midwest. The exact shape of the graph will change based on soil texture, organic matter content and the types of minerals present in the soil.



**Figure 1.** The relationship between percent base saturation and soil pH in typical Midwestern alfisol when calcium is the dominant basic cation.

This is the relationship found when calcium is the dominant basic cation on the exchange sites, as is the case in most Midwestern soils. In some areas of Kansas, particularly where irrigation with marginal quality water containing sodium has been practiced, sodium has become a significant portion of the exchangeable cations. Only when sodium is present will soil pH above 8.5 occur. If soil pH's higher than 8 are found in routine soil testing, an exchangeable sodium test should be requested.

### SOURCES OF ACIDITY

Some soils are acidic because of the composition of the parent material from which they were formed. Other soils become acid by a number of processes which occur as a result of normal cropping. Cropping and use of nitrogen fertilizers are the two main sources of soil acidity while another contributor is rainfall. The net result is that hydrogen, and aluminum (acidic cations) replace calcium, magnesium, and potassium, (basic cations) on the soil cation exchange complex, resulting in a lower base saturation and soil pH.

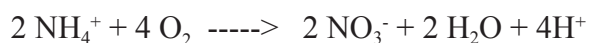
**Crop Removal.** Calcium, magnesium, and potassium are essential nutrients for plant growth. Their uptake by plants, and subsequent removal through harvest, can have an acidifying effect on soils. The amount of these nutrients removed by cropping depends on: a) crop growth, b) part of crop harvested, and c) stage of growth at harvest. Removal is much greater for hay or silage crops than for grain crops, as shown in **Table 1**.

**Table 1.** Calcium, magnesium, and potassium content of common crops.

Crop	Production	Calcium	Magnesium	Potassium
<b>Hay Crops</b>	<b>ton/a</b>	<b>-----lb./a-----</b>		
Alfalfa	6	180	28	240
Red Clover	3	75	22	100
Orchardgrass	3	22	10	110
<b>Grain Crops</b>	<b>bu/a</b>			
Corn--grain	150	2	8	25
Soybeans--seed	50	8	8	45
Wheat--grain	50	1	4	13

Source: *Feeds and Feeding*. Morrisons 22nd Edition

**Fertilizers.** Nitrogen fertilizers have a greater acidifying effect on soils than any other source of acidity. Most commonly used nitrogen fertilizers contain ammonium nitrogen (urea is an ammonium forming material). Soil bacteria convert ammonium (NH<sub>4</sub><sup>+</sup>) to nitrate (NO<sub>3</sub><sup>-</sup>) through a biochemical process called nitrification. Hydrogen (H<sup>+</sup>) is released in this process, and the freed hydrogen ions cause an increase in acidity.



Nitrification

**Table 2** shows the calculated amount of aglime, expressed as Effective Calcium Carbonate (ECC), needed to offset the acidity potential of several common nitrogen containing fertilizers. It is evident that applying more nitrogen fertilizer than a crop can take up is not only wasteful and expensive from the nitrogen standpoint but also increases the cost of a liming program.

The second potential acidifying effect from nitrogen comes from nitrate that is not taken up by the growing crop. Nitrates are very soluble and if not taken up by plants, will move downward with soil water and be carried below the root zone. The negatively charged nitrate ions take other positively charged ions, most likely calcium and magnesium since they are normally present in the largest quantities, with them and their removal in this manner has the same acidifying effect on soils as removal by a crop.

**Table 2.** Amount of aglime (pounds ECC) required to neutralize acidity created by nitrogen fertilizer.

Fertilizer	N concentration	Pounds of 50% ECC lime needed to neutralize the acidity from 1 lb. of actual N
Ammonium nitrate	34% N	3.6
Anhydrous ammonia	82% N	3.6
Urea	46% N	3.6
UAN solutions	28-32% N	3.6
Ammonium sulfate	21% N	7.2
Monoammonium phosphate	11-12% N	7.2
Diammonium phosphate	18% N	5.4

**Rainfall.** Soils will naturally become acid even in the absence of crop removal or fertilizer applications, because rainfall is a natural source of acidity. Natural rain, without any pollution from man, has a pH of about 5.4. The actual pH of rainwater will be a function of the CO<sub>2</sub> level in the atmosphere and any pollutants such as N or S compounds in the atmosphere. Prior to the development of current air pollution control equipment, the acidity level of rainfall was very low, especially in heavily industrialized, urban areas. While many of the pollutants have been removed, the acidity of rainfall is still dropping as CO<sub>2</sub> levels in the atmosphere continue to increase. The actual amount of acidity supplied through rainfall each year is very, very small. But over long periods of times, centuries, this will cause soils in a humid climate to become acid. The lower the CEC of soils, the less well buffered they are, and the more rapidly the pH will drop. Most of the soils in humid parts of the United States are naturally slightly acid, while in the lower rainfall regions, soil pH tends to be higher naturally. Soil pH in Kansas is a great example of this trend. In Eastern Kansas, where rainfall will average 35-45 inches per year, almost all soils, with the exception of river bottoms, are slightly acid to acid (pH in the 5.0 to 6.5 range) and a high percentage will call for lime application when tested. In western Kansas and Eastern Colorado however, rainfall is much lower, 15 to 20 inches per year, and most soils have high pH, and many are calcareous and contain free lime.

Acid rain receives considerable publicity but is not a significant factor in a farmers liming program, because most agricultural soils are well buffered. When I worked at Purdue, 20-30 years ago, the acid rain of the Ohio River Valley, a heavily developed area home to large numbers of coal fired electrical generators, had a pH of about 4.3 to 4.5, over ten times more acid than natural rainfall. This additional acid was produced by the sulfur and nitrogen oxides in the air reacting with water, and it amounted to about half a pound of acid per acre per year.

There may have been as much as another half pound of acidity added by dry deposition (airborne particles or smoke and ash containing acid forming N and S compounds) deposited on soils in this same area each year. Thus, up to 1 pound of total acidity per acre per year was probably received each year. Neutralizing this would require about 100 pounds of ECC as limestone per acre per year. Thus a ton or two of lime every 20 years would neutralize the effect of both acid rain and dry deposition.

Note that this same N and S in rain and dry deposition producing a pound of acidity each year also provided about 10 pounds of N and 20 pounds of sulfur annually. (The area where I grew up received 40-60 pounds of sulfur annually from our friends in the heavy industry concentrated along Lake Michigan). This is the primary reason that many farmers in the eastern US did not have to routinely fertilize with sulfur. But today, sulfur deficiencies are becoming more frequent and sulfur fertilization is a new topic in many fertilizer programs.

In Kansas, air quality is much higher, due primarily to lower populations, fewer cars and less industrial activity. Rainfall has a pH much closer to 5.5, and deposition in wet and dry forms of acidity, N and S is much lower. This is one reason, Kansas farmers have needed to consider S as a potentially responsive nutrient for many years.

**Other Sources of Acidity.** In addition to the acidifying effects of rainfall, organic acids, similar to vinegar, are produced in the soil when plant residues and organic matter decompose. These weak acids react and combine with nutrients such as calcium, magnesium, and potassium and move down through and below the root zone with rainfall. Hydrogen is released from these organic acids and replaces basic cations causing the soil in the leached zone to become even more acid. Examples of this process are found in Karst topography, where limestone rock is found just a few feet below an acid surface soil. The long-term leaching of these acids has dissolved sufficient limestone and caused a collapse of the surface soil creating sinkholes.

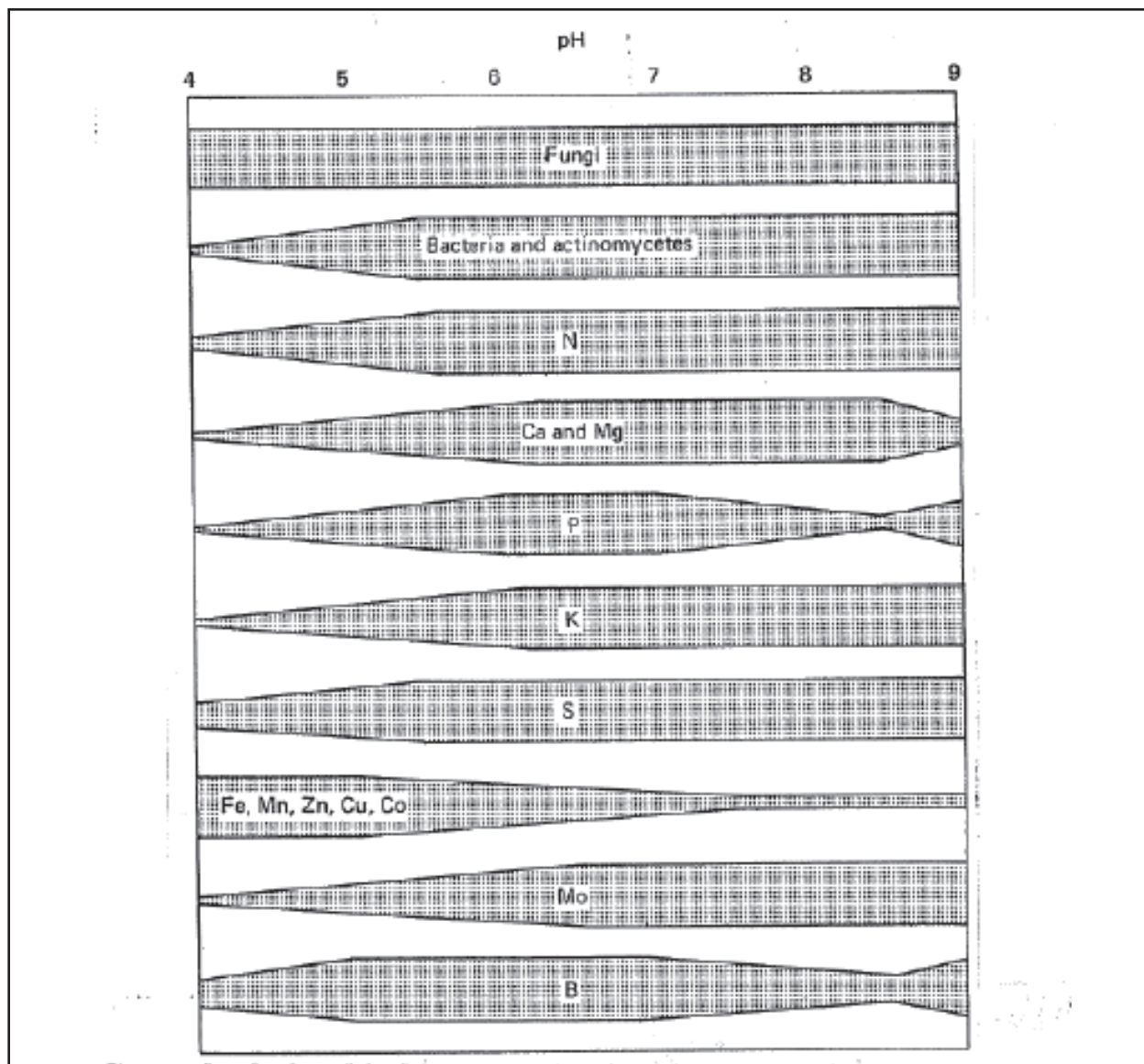
Surface runoff can also carry calcium, magnesium and other nutrients in solution, and these nutrients can be physically removed in the erosion process. Both actions leave the remaining soil more acid.

## **BENEFICIAL EFFECTS FROM LIMING**

Soil acidity has a direct effect on availability of most essential plant nutrients. **Figure 2** shows the general effect of pH on plant nutrient availability. The pH range for highest availability of most nutrients is between 6.0 and 7.0. Deficiencies can be observed at both low and high pH's. Manganese and iron can also become toxic at low pH. Although aluminum is not an essential nutrient, its availability also increases rapidly as the soil pH drops below 5.0. Too much aluminum in solution will restrict root growth and plant development.

Many soil microorganisms do not function effectively in acid soils. As soil pH levels decline so does the activity of the organisms which decompose organic materials such as crop residue, releasing nutrients to plants. Although many of these organisms function best at soil pH levels of 7.0 and above, their effectiveness does not drop rapidly until pH levels drop below 6.0. Decomposition of organic matter also contributes to aggregation of soil particles which provides for good soil tilth, aeration, and drainage. The survival and effectiveness of the bacteria which enter legume roots and fix nitrogen (nodulation) is also highest at pH levels of 6.5 to 7.0 and declines rapidly when pH levels fall below 6.0.

The performance of some herbicides, particularly the triazines, is affected strongly by soil pH. As pH levels drop below 6.0, the effectiveness of atrazine for example, is greatly reduced. On the other hand, the activity of some compounds may be greatly enhanced at high pH. Metribuzin, a common soybean herbicide is not normally labeled for use on calcareous soils because it is too active and causes crop injury. Carryover or persistence of some materials is also affected by soil pH. Chlorimuron, Classic, is not used at high pH because the compound is persistent and carryover damaging to rotation crops is possible. Again, maintaining a soil pH in the range of 6.0 to 7.0 optimizes the performance of many commonly used herbicides and minimizes potential problems.



**Figure 2.** General relationship between soil pH and the availability of nutrients in the soil (from Brady, 8th edition).

### SOIL SAMPLING FOR LIMESTONE NEEDS

Consider soil buffer capacity. The amount of lime needed to obtain a change in soil pH, (buffering capacity) varies with the soils cation exchange capacity. Cation exchange capacity refers to the amount of the soils negative charge and the amount of positively charged ions such as calcium and magnesium or hydrogen which can be held. Cation exchange capacity is a function of soil organic matter and clay content. The higher the organic matter content and the heavier the soil texture, the higher the soils CEC. Since soil pH is a reflection of the percent acids on the exchange sites, acidic soils with a high CEC contain more acidity than a low CEC soil of the same pH. Thus more lime will be required to get the same change in pH of a high CEC soil than a low CEC soil.

Many fields vary in organic matter content and texture. It is important that soil samples be taken to select and identify variations that exist in a field rather than to mix everything together into one sample and then obtain an average. This process may require carefully selecting sample locations within a field to minimize the variation and more efficiently use lime. A detailed soil survey is available in most of the United States and provides a helpful guide to soil difference that can be expected in a field. WebSoilSurvey is a great tool to use. Out in the field, soil samples should be separated primarily on the basis of soil color differences which reflect variations in organic matter. Separate soil samples should be taken also where the texture of soil surface varies widely. Historical differences in management between parts of a field also should be considered. Old aerial photographs can provide excellent information on previous farming activities.

With the advent of Geographic Positioning Systems and yield monitors, a number of other methods to assess soil variability have also become widely used. Management zone sampling has become popular among farmers who utilize yield monitors. This system entails identifying management zones, or areas with similar yields and soils, and using these as soil sampling areas.

Grid sampling has also been used in some areas as a routine way to estimate soil variability. Grid sampling systems have been recommended by the University of Illinois since the 1920's. Grid cells will routinely vary from 1 to 5 acres in size. Lime and fertilizer may be applied directly based on the sample results from the grid, or the data may be analyzed using geo statistical techniques to develop nutrient maps. As a general rule, I prefer to use Management Zones in fields with significant slope and differences in soil depth, past erosion and water holding capacity. I prefer grid samples in nearly flat to gently rolling fields with little obvious soil variability.

Use the appropriate sampling depth. Soil samples for routine pH, P and K recommendations for grain crops are normally taken using a 6 to 7 inch sampling depth. However, sample depth needs to be adjusted when working with conservation tillage systems or in forage fields. If a moldboard plow or chisel plow is used once every four or five years, take samples for fertilizer and lime recommendations at a 6 to 7 inch depth. While most of the soil mixing occurs in the upper one half to two thirds of the chisel depth (depending on the type of chisel points used), and nutrient stratification is known to occur, enough mixing occurs to get lime, and lime effects, throughout most of the surface soil.

Where fields are in continuous no-till for four years or more, especially where nitrogen fertilizer is broadcast or sprayed on the soil surface, or in pastures and hayfields, soil samples for pH and lime requirement should be taken from the top 2 to 4 inches of soil. This will identify the acidity stratified near the surface, which is also the acidity which a surface application of lime will neutralize. An adjustment of lime recommendations will be necessary in these situations also. Most soil testing laboratories make lime recommendations assuming that the lime will be mixed with 6 to 7 inches of soil. Since lime is relatively insoluble, when applied on the surface the effects are limited to the top 3 to 5 inches of soil. Thus normal lime rates should be cut in half when surface applying lime to no-till fields, pastures or hay fields.

When to sample. Surface soil pH fluctuates during the growing season according to soil moisture levels. This is due to variations in salt content in the soil surface. As water evaporates from the soil surface, soil pH drops due to soluble salt accumulations. These salts are primarily calcium, magnesium and potassium salts of nitrate, sulfate and chloride. As the soil rewets and the salts move down through leaching, the soil pH goes back up. The lower the cation exchange capacity of the soil, the bigger this change in pH is likely to be. It is not unusual for the pH of a sandy, low CEC soil to drop as much as 0.5 pH units during the summer, while dark colored silt loams may show little or no measurable change. It is recommended that soil samples be collected

when soils are moist, to minimize variation from year to year. An alternative approach to get around seasonal variations in pH due to salts is to add a known amount of salt to the sample when measuring pH in the lab. Commonly referred to as salt pH, the technique is used in several states including Missouri and Indiana. Salt pH is generally lower than the pH measured in water. Therefore if working in an area where salt pH is used, be sure to use the correct interpretation information.

### MEASURING ACIDITY AND LIME REQUIREMENT

Soil testing labs routinely use a two step process to measure soil acidity and determine lime requirement. The first step is to mix a sample of dry soil with deionized water and measure soil or water pH. If the soil-water pH falls more than 0.2 pH units below the recommended pH level for the crop being grown, lime is normally recommended. The recommended pH varies with both crop being grown and soil characteristics. Sub soil depth and pH are important factors which also influence response to lime. The recommended pH's for different crops grown in different areas in Kansas for an example, are summarized in **Table 3**.

**Table 3.** Recommended soil pH for the principle crops grown in Kansas.

Crop	Recommended pH in Kansas			
	SE	NE	Central*	Western*
Alfalfa and most clovers	6.8	6.8	6.0	6.0
Red clover and trefoil	6.0	6.0	6.0	6.0
Most forage grasses	6.0	6.0	6.0	6.0
Soybeans	6.4	6.0	6.0	6.0
Corn, small grains, canola	6.0	6.0	6.0	6.0

\* in Central and Western Kansas where lime is not readily available, a recommended pH of 5.5 is used for most crops other than alfalfa.

**Soil pH vs. Lime Index.** The pH measured in water reflects the environment that plant roots are exposed to and is routinely used to determine if lime is needed. Water pH is not a good measure of the amount of lime needed to change soil pH however. The water pH is a reflection of the percent base saturation of the soil, and the acidity in the soil solution. But it does not give any indication of the quantity of acids or bases that are present, or the buffer capacity of the soil. To determine the amount of lime that will be required to neutralize the acidity on the exchange sites a buffer test is commonly used. Buffers are solutions which are designed to resist change in pH. By mixing a buffer of known pH with an acid soil and measuring the drop in pH that results, one can calculate the amount of lime needed to reach the desired pH.

In most of the Midwest, the SMP or Sikora buffers are used to estimate the lime requirement of mineral soils. Other buffers such as the Woodruff or Mehlich are also used in the region. The SMP buffer, developed in Ohio for use on silt loam and silty clay loam soils with moderate to high CEC, is adjusted to an initial pH of 7.5, and upon mixing the buffer with an acid soil the pH drops. The more the pH drops, the more lime will be required. Most soil test reports will give the measured pH of the soil:buffer mixture as either the SMP Buffer pH or the Lime Index. Lime



index is created from buffer pH by removing the decimal point i.e. a buffer pH of 6.4 is a lime index of 64.

The lime recommendations for mineral soils based on the SMP buffer test used in Kansas are summarized in **Table 4**. The rates are given as pounds of Effective Calcium Carbonate as aglime, and assume that primary tillage such as moldboard or chisel plowing will be used to incorporate the lime to a 6 to 7 inch depth. For no-till or conservation till systems or for lime applications to established forages, mixing of lime with the soil is minimal, and reaction and change of pH only occurs in the surface 2-3 inches of soil. Therefore the lime rates should be reduced 50% to avoid raising the pH of the surface higher than desired. The recommended lime application rates for no-till or forage production are given in **Table 5**.

**Table 4.** Pounds of ECC from Aglime needed to raise the soil pH to the desired level based on the SMP buffer test, Conventional tillage system.

Buffer pH	Lime Index	-----Desired pH level-----			
		6.8	6.4	6.0	5.5
		----- lb ECC/acre-----			
7.4	74	0		0	0
7.2	72	750	575	375	250
7.0	70	1,750	1,325	875	500
6.8	68	3,000	2,250	1,500	750
6.6	66	4,500	3,375	2,250	1,125
6.4	64	6,250	4,700	3,125	1,625
6.2	62	8,250	6,200	4,125	2,000
6.0	60	10,250	7,700	5,125	2,625
5.8	58	12,500	9,375	6,250	3,125
5.6	56	15,250	11,800	8,325	3,750
5.4	54	18,000	13,500	9,000	4,500
5.2	52	20,000	15,200	10,375	5,250

If the lime recommendation is for 6,000 tons per acre or less, the lime can be applied at any time in a cropping sequence. When the lime recommendation exceeds 6,000 lbs ECC per acre, apply half the lime before primary tillage to improve mixing with the total tillage zone, and then re-test in 12 to 18 months to determine the remaining amount needed.

**Low CEC Soils.** Sandy soils, especially those with low organic matter content, have a low CEC and are very weakly buffered. In some cases the water pH may be below that recommended for the crop or rotation being grown, but the buffer pH may not indicate a need for lime. This occurs because these soils do not have enough reserve or exchangeable acidity to lower the pH of the buffer solution. When this occurs, a recommendation used in Kansas has been to apply 750 lbs ECC per acre if the water pH is more than 0.3 pH units below desired or 1,500 lbs ECC per acre if the pH is more than 0.6 pH units below desired.

In areas where the majority of the soils have low CEC, <10, other buffer tests such as the Mehlich are commonly used to make lime recommendations to avoid this issue.

## QUALITY OR EFFECTIVENESS OF LIMING MATERIALS

How effective a liming material will be in correcting soil acidity is dependent on two factors : chemical purity and fineness or particle size.

**Purity.** Ag lime materials vary in their composition and thus their capacity to neutralize acidity. Calcium carbonate equivalence (CCE) is the standard for measuring the chemical effectiveness of liming materials. Pure calcium carbonate is assigned a Calcium Carbonate Equivalence (CCE)

**Table 5.** Pounds of ECC from Aglime needed to raise the soil pH to the desired level based on the SMP buffer test, No-till or established pastures or hayfields with no incorporation.

Buffer pH	Lime Index	-----Desired pH level-----			
		6.8	6.4	6.0	5.5
		----- lb ECC/acre-----			
7.4	74	0	0	0	0
7.2	72	375	300	200	125
7.0	70	875	675	450	250
6.8	68	1,500	1,125	750	375
6.6	66	2,250	1,700	1,125	575
6.4	64	3,125	2,350	1,575	825
6.2	62	4,125	3,100	2,075	1,025
6.0	60	5,125	3,850	2,575	1,300
5.8	58	6,250	4,700	3,125	1,575
5.6	56	7,625	5,875	4,175	1,875
5.4	54	9,000	6,675	4,500	2,250
5.2	52	10,000	7,600	5,200	2,625

value of 100%. Some liming materials have a greater capacity to react with and neutralize acidity, such as calcium magnesium carbonate, or dolomite, which has a CCE of 108%. Most ag limes contains a mixture of both calcium and magnesium carbonates along with varying levels of other impurities. The CCE of most commercially available limes generally ranges between 85 and 107. Many states have lime regulations requiring a minimum CCE. These values generally range from 80 to 90% CCE.

**Fineness or particle size.** This refers to the size of the individual lime particles and is important because it governs how quickly acidity will be corrected. Most liming materials contain a mixture of particle sizes, from dust to fine-gravel like. Small particles dissolve rapidly and react quickly due to their high surface area. Coarse particles react very slowly and may be of little value in correcting an acidity problem.

Fineness of ag lime is determined by passing the material over a set of sieves (screens) of different sizes. Sieve size is expressed in terms of the number of openings per linear inch, an 8 mesh sieve has 8 openings per inch. **Table 5** shows the rate at which different size lime particles dissolve.

In the Midwest 8, 30 and 60 mesh sieves are commonly used to determine fineness. Specific sieve sizes are often specified in a states lime laws or regulations, along with the efficiency factors assigned to those particle sizes (**Table 7**). The State of Kansas has a lime labeling law, which requires that the percent of the tested lime passing the 8 and 60 mesh sieves be provided to the customer, along with the CCE (calcium carbonate equivalence) of the lime stone. K-State suggests that a minimum of 80% pass an 8 mesh sieve and 25% pass a 60 mesh sieve for reasonable lime performance.

**Table 6.** Relative effectiveness of different size limestone particles.

Particle Size	Percent Dissolving in		
	1 year	4 years	8 years
Larger than 8 mesh	5	15	15
Pass 8 mesh, held on 30 mesh	20	45	75
Pass 30 mesh, held on 60 mesh	50	100	100
Smaller than 60 mesh	100	100	100

**Table 7.** Efficiency factors used to determine the effect of Lime particle size on Effective Calcium Carbonate content of lime, ECC.

Particle Size	Efficiency Factor
> 8 mesh	0
8-60 mesh	0.5
< 60 mesh	1.0

**Estimating lime quality, ECC.** The ultimate effectiveness of ag lime is determined by the interaction of purity and fineness. Since both fineness and purity vary from one producer to another, there have been several systems devised to compare limes for the purpose of economics and adjustment of recommended rates for quality. In Kansas, lime needs are expressed in pounds of Effective Calcium Carbonate needed per acre, and lime quality is calculated as pounds of effective calcium carbonate per ton. ECC per ton of ag lime is calculated using the following formula:

$$ECC = \frac{(\% <8 - >60 \times 0.5) + (\% <60 \times 1.0) \times CCE \times 2000}{100}$$

This formula gives pure calcitic limestone (CCE = 100% or 1.00) ground so that all particles pass a 60 mesh sieve, an ECC of 2,000 as indicated in the following example:

$$\text{ECC} = \frac{0 + 100 \times 1.0 \times 2000}{100}$$

An example of a more typical aglime found today would be a dolomite with a CCE of 90%, 0.9, ground so that 80% passed an 8 mesh and 40% passed a 60 mesh. The ECC of that lime would be:

$$\text{ECC} = \frac{(90 \times 0.5) + (40 \times 1.0) \times 0.9 \times 2000}{100}$$

$$= \frac{(45 + 40) \times 0.9 \times 2000}{100}$$

$$= 1530 \text{ pounds ECC per ton}$$

Rather than expressing lime quality as pounds of ECC per ton, some states or organizations will utilize ECCE, Effective Calcium Carbonate Equivalent. This expresses the ECC as a percentage rather than pounds per ton. In the calculation above, simply divide the ECC by 2000 pounds per ton to get the ECCE percent. Or  $1530/2000 = 0.765 \times 100 = 76.5\%$ . ECCE Limestones are often referred to as percent limes, where ECCE is commonly used. Other similar systems such as the Relative Neutralizing Value, RNV are also used in the Midwest.

## LIMING SOURCES

Several liming materials are marketed, and it is important to recognize differences among them.

**Ground Aglime (dry).** The most common liming material Ag Lime Limestone rock is crushed and ground into a material known by several names including: Aglime, Agrilime, Ag stone, Ground Agricultural Limestone and Lime. Ground aglime is the most widely used liming material in the midwest, as it is easy to transport and apply. The calcium in limestone is in the carbonate form and most Kansas limestones also contain some magnesium carbonate. Calcium content ranges from 15 to 40% and magnesium content ranges from 0 to 15%. Limestone with less than 5% magnesium is designated as “calcitic limestone”. Limestone with more than 5% magnesium is referred to as “dolomitic limestone”.

**Fluid Lime (liquid lime).** In recent years a product called fluid or liquid lime has been marketed in some areas. The product is prepared by mixing very finely ground aglime (100% passing a 100 mesh sieve and 80-90% passing a 200 mesh sieve) with water along with a suspending agent (attapulgite clay). Often this product is produced using spent lime from water treatment plants. The material is applied with a liquid fertilizer applicator. Aglime content of liquid lime normally varies from 50 to 70%, with the lower value most common.

The main advantage for liquid lime is that a more uniform application can be made in the suspension form. Claims are also made that liquid lime will raise the soil pH faster than standard dry aglime and that much less material is needed because it is very finely ground. Both statements

are partially true. For the first few months after application, the soil pH will rise faster where liquid lime is applied. But, within one year soil pH changes will normally be equal for liquid and dry sources applied at equivalent rates of ECC.

The relative speed at which a particle reacts is a function of surface area. The smaller the individual particles, the faster the particle will react and change pH. Particles that are smaller than 60 mesh are considered to be 100% available and will be effective in changing soil pH within a few months after application. Grinding particles finer than 60 mesh may speed the rate of reaction, but it will not alter the overall effectiveness of the lime.

Higher cost is the main disadvantage of liquid lime. This is primarily due to the additional cost of grinding the material fine enough to keep it in suspension, the cost of the suspending agent and transportation costs for the water used in the suspension. A common application rate is 1000 pounds per acre-500 pounds water and 500 pounds aglime. This rate would be equivalent to 1000 pounds per acre of a typical 50% aglime (1000 pounds ECC per ton)

**Pelletized Lime (pel lime).** To avoid the dust problems associated with spreading very fine particles, finely ground aglime can be compressed into pellets or granulated using a binding agent. The resulting product can then be spread in a manner similar to dry fertilizers. Individual pellets are readily dispersible in water and like liquid lime, will react very quickly in soil. Application rates can also often be reduced one-third to one-half because of the fineness of the particles used to make the granule, and the high ECC of the product (often in the 1,800 to 1,900 lbs ECC per ton range). Claims that a few hundred pounds can substitute for a ton of aglime have not been substantiated by land grant university research. Likewise, the practice of banding 200 to 400 pounds per acre of pelletized lime in the row as a starter fertilizer may be a means of supplying calcium or magnesium to the crop, but would have no effect on other key processes controlled by soil pH, and has only a limited potential for creating a yield increase capable of paying for the product.

**Marl.** This liming material is soft, unconsolidated lime material made up of marine shell fragments and calcium carbonate and found under many shallow organic soils. Marl also commonly contains clay and organic matter as impurities and is mined wet and sold by the cubic yard because of the high moisture content. As a general rule, two cubic yards of marl has a neutralizing value equivalent to one ton of aglime. Uniform spreading is difficult unless the material is dried and ground, which increases the cost of the product. Use is generally confined to areas very near marl deposits. Since marl contains no magnesium, repeated applications of marl may result in soils deficient in magnesium. Deficiencies can be prevented by occasional liming using dolomitic limestone.

## **ALTERNATIVES TO LIMING TO A SPECIFIC PH**

Correction of soil acidity by liming to a specific pH is a well-established practice in many parts of the world. However lack of reasonably priced lime in areas such as South America, Africa and the Central and Southern plains of the US has caused agronomists to take a second look at liming practices.

In tropical areas of the world such as parts of South America, South Asia and Africa liming to reduce aluminum toxicity has become common place. This practice involves extracting with KCl, and applying 1 to 2 times the equivalents of Al of lime, depending on the sensitivity of the crop(s) being grown to Al toxicity. On the low CEC, highly weathered soils in these areas, this generally will result in a water pH of 5.2 to 5.5, lower than normally recommended in the Midwest.

In the Southern Great Plains, lime has also historically not been available in many areas, and wheat is the traditional cash crop grown. The majority of these soils are strongly acid on the surface, but higher pH in the subsoil, often being slightly acid to neutral within 6 to 8 inches of the surface. An application of P fertilizer in the row at seeding, will react with soluble aluminum determining the amount of exchangeable aluminum present on the CEC of the soil, normally by in the root zone allowing seedlings to root through the acid, Al toxic surface, into the more favorable conditions deeper in the profile.

Plant breeders have also been successful at developing acid tolerant wheat varieties which can withstand fairly high levels of Al in solution. By combining the two practices, band application of 20-40 lbs  $P_2O_5$ /acre with an acid tolerant variety, Great Plains wheat growers have been able to produce high wheat yields in fields with a surface pH as low as 4.5 to 4.7, and soluble Al levels of 125 ppm, well above that known to be toxic to wheat.