SECTION CONTENTS:

Soil pH

What is soil acidity? In simple terms, an acid is defined as a substance that tends to release hydrogen ions (H+). Conversely, a base is defined as a substance that releases hydroxyl ions (OH^-).

All acids contain hydrogen ions and the strength of the acid depends upon the degrees of ionization (release of hydrogen ions) of the acid. Some acids are classified as strong acids because they are highly ionized (release of H ions) — when dissolved in water. Examples of strong acids are hydrochloric acid (HCl), sulfuric acid (H_2SO_4) and nitric acid (HNO_3). Other acids are classified as weak acids because they slowly ionize (release H ions). Examples of weak acids are carbonic acid (H_2CO_3), citric acid ($H_8C_6O_7$).

When clay colloids are saturated by H ions, they behave as a weak acid. The more hydrogen ions held by the exchange complex of a soil in relation to the basic ions (Ca, Mg, K) held, the greater the acidity of the soil. (Al also contributes to soil acidity, but for simplicity further discussion of soil acidity will be limited to H as the cause of soil acidity.

Table 4.1. Desirable Soil pH for Optimum Crop Production pH Range

	pH Range	
5.0 - 5.5	5.5 - 6.5	6.5 - 7.0
Blueberries	Barley	Alfalfa
Irish potatoes	Bluegrass	Some clovers
Sweet potatoes	Corn	Sugar beets
	Cotton	
	Fescue	
	Grain sorghum	
	Peanuts	
	Rice	
	Soybeans	
	Wheat	
	Watermelon	

The desirable pH range for optimum plant growth varies among crops. While some crops grow best in the 6.0 to 7.0 range, others grow well under slightly acid conditions. Soil properties that influence the need for and response to lime are different in different regions. A knowledge of the soil and the crop are important in managing soil pH for the best crop performance. A general categorization of desirable pH ranges for different crops is shown in Table 4.1.

Soils become acid when basic elements, such as calcium, magnesium, sodium, and potassium held by soil colloids are replaced by hydrogen ions. Soils formed under conditions of high annual rainfall are more acid than are soils formed under more arid conditions. Most southeastern soils were formed under the former condition. Consequently, they are inherently more acid than soils of the midwest and far west.

Soils formed under low rainfall conditions tend to be basic with soil pH readings around 7.0 However, intensive farming over a number of years with nitrogen fertilizers or manures can result in soil acidification. In the wheat growing regions of Kansas and Oklahoma for example, soil pH of 5.0 and below, aluminum toxicity in wheat, and good response to liming have been documented in recent years.

Soil Acidity

Rainfall Contributes to Soil Acidity

Water (H_2O) combines with carbon dioxide (CO_2) to form a weak acid — carbonic acid ($H_2CO_3^-$). The weak acid ionizes, releasing hydrogen (H^+) and bicarbonate ($HCO_3^=$). The released hydrogen ions replace the calcium ions held by soil colloids, causing the soil to become acid. The displaced calcium (Ca^{++}) ions combine with the bicarbonate ions to form calcium bicarbonate, which, being soluble, is leached from the soil. The net effect is increased soil acidity.

Nitrogen Fertilizers and Many Plants Contribute to Soil Acidity

Nitrogen sources (fertilizers, manures, legumes) which contain or form ammonium increase soil acidity unless the plant directly absorbs the ammonium ions. The greater the nitrogen fertilization rate with these sources, the greater the soil acidification. As ammonium in converted to nitrate in the soil (nitrification), H ions are released. For each pound of nitrogen as ammonium or forming ammonium in urea, ammonium nitrate, and anhydrous ammonia, it takes approximately 1.8 pounds of pure calcium carbonate to neutralize the residual acidity. Also, the nitrate that is provided or that which forms, can combine with basic cations like calcium, magnesium, and potassium and leach from the topsoil into the subsoil. As these bases are removed and replaced by H ions, soils become more acid.

Legumes like soybeans, alfalfa and clovers tend to take up more cations in proportion to anions. As a consequence, H ions are excreted from their roots to maintain electrochemical balance within their tissues. The result is a net soil acidification. This helps to explain the decline of alfalfa and other legumes as the stands age and liming is neglected.

How is Soil Acidity Measured?

Soil acidity is determined by a measurement of the hydrogen ion concentration of a particular soil. A pH meter is the instrument generally used by soil testing laboratories in measuring soil acidity. Generally, a small portion of the soil sample is mixed with water in a 1 to 1 or a 2 to 1 ratio and stirred. After the soil solution has set for approximately 30 minutes, a glass electrode and reference electrode are dropped into the soil-water mixture and the soil pH is determined. The measurement scale used in determining soil acidity is the pH scale which ranges from 0-14. A soil pH of 7.0 indicates a soil is neutral in reaction. Any number below 7.0 denotes soil acidity and numbers above 7.0 denote soil alkalinity. These measurements are a logarithmic factor. Therefore, a soil with a pH of 6.0 is 10 times more acid than a soil with a pH of 7.0. A soil having a pH of 5.0 is 100 times more acid than a soil pH of 7.0, etc.

Buffer pH

In making accurate lime recommendations, soil test laboratories must determine both the active and the potential acidity of a soil sample. The active acidity is determined by use of a pH meter and the potential acidity is determined by the buffer pH procedure. The buffer pH is the number shown under the heading "BpH" on the soil test report. This number is derived by adding a "buffer" solution to the soil sample after the normal soil pH is read. The pH meter is then used to measure the decrease in the pH of the buffer solution due to the H held by the soil. The change in pH of the buffer solution after it has been added to the soil and the water pH determine the lime requirement for the soil.

There are numerous buffer solutions in use. The Adams-Evans buffer solution was designed for use in soils with relatively low CEC and organic matter. The solution has an initial pH of 8.0. The buffer solution commonly used in the Midwest is referred to as the SMP Buffer Solution. It has an initial pH of 7.5.

Subsoil Acidity

Even if the top six inches of soil show a pH above 6.0, the subsoil may be extremely acid. When sub-soil pH’s drop below 5.0, aluminum and manganese in the soil become much more soluble and in some soils may be toxic to plant growth. Cotton and, to some extent, soybeans are examples of crops that are sensitive to high soluble aluminum levels in the subsoil and crop yields may be reduced under conditions of low subsoil pH, as shown in Table 4.2.

Table 4.2: Effect of Subsoil Acidity on Yields of Seed Cotton (Alabama Experiment Station - Auburn University[1])

SOIL TYPE	YEARS	SUBSOIL pH 6-12 IN.	AVERAGE YIELD lb/acre
Norfolk Fine Sandy Loam	1962-64	5.0	1620
		5.5	2680
		6.4	2620
Magnolia Fine Sandy Loam	1964-66	4.9	1710
		5.4	2040
		6.0	1810
Greenville Fine Sandy Loam	1965-66	4.2	1380
		4.4	1770
		5.2	2170
		5.9	2150

[1]Soil pH of Surface Soil (0-6") ranged from 6.0 to 6.5

Results from this experiment show that cotton yields were significantly reduced when limed and fertilized surface soils were underlain by strongly acid (pH 5.0 or less) subsoils. Cotton roots failed to grow extensively in the strongly acid subsoil resulting in smaller plants and lower yields. Plants in the most acid subsoils showed signs of wilting in midseason within 3 or 4 days following a rain, whereas those on moderately acid subsoils were able to withstand droughts of 10 to 14 days without wilting.

On the basis of this and other research, it would be advisable for farmers who have observed areas of stunted plants in their fields to take a subsoil sample in these areas. If the soil pH is extremely acid (below 5.2) lime should be applied early in the fall and turned as deep as possible.

Liming Acid Soils Pays

Correcting soil acidity by the use of lime is the foundation of a good soil fertility program. Lime does more than just correct soil acidity. It also (1) supplies Ca, and Mg if dolomitic lime is used, which are essential plant nutrients; (2) it makes other essential nutrients more available; and (3) it prevents elements such as Mn and Al from being toxic to plant growth.

Table 4.3: Limestone Makes Fertilizer Work. Fertilizer Efficiency Goes Up as Soil Acids Go Down

SOIL ACIDITY	NITROGEN	PHOSPHATE	POTASH	FERTILIZER WASTED
Extremely Acid 4.5 pH	30%	23%	33%	71.34%
Very Strong Acid 5.0 pH	53%	34%	52%	53.67%
Strongly Acid 5.5 pH	77%	48%	77%	32.69%
Medium Acid 6.0 pH	89%	52%	100%	19.67%
Neutral 7.0 pH	100%	100%	100%	00.0%

Liming Materials

Liming materials are materials that contain calcium and/or magnesium in forms, which when dissolved, will neutralize soil acidity. Not all materials which contain calcium and magnesium are capable of reducing soil acidity. For instance, gypsum ($CaSO_4$) contains Ca in appreciable amounts, but does not reduce soil acidity. The reason it does not is because when gypsum hydrolyzes in the soil, it converts to a strong base and a strong acid as shown in the following equation:

$$CaSO_4 + 2H_2O = Ca\,(OH)_2 + H_2SO_4$$

These two products formed, $Ca(OH_2)$ and H_2SO_4, neutralize each other and the result is a neutral soil effect. On the other hand, when calcitic ($CaCO_3^-$) or dolomitic lime ($Ca\,Mg\,(CO_3)_2$ is added to the soil, it hydrolyzes (dissolves in water) to a strong base and a weak acid.

$$CaCO_3 + 2H_2O = Ca\,(OH)_2 + H_2CO_3$$

Calcium hydroxide is a strong base and rapidly ionizes to CA^{++} and OH^- ions. The calcium ions replace absorbed H ions on the soil colloid and thereby neutralize soil acidity. The carbonic acid formed (H_2CO_3) is a weak acid and slowly and partially ionizes to H^+ and CO_2^{-2} ions. Therefore, the net effect is that more Ca than H ions are released in the soil and consequently soil acidity is neutralized.

Calcitic Limestone

Ground limestone which contains mostly calcium carbonate and generally less that 1 to 6% magnesium. Its neutralizing value depends on its purity and fineness of grinding.

Dolomitic Limestone

Ground limestone which is a mixture of calcium carbonate and magnesium carbonate. In some states, it must contain at least 6% Mg to be classified as dolomitic lime. Its neutralizing effect also depends upon its purity and fineness of grinding.

Hydrated Lime

Hydrated Lime ($Ca(OH)_2$) is calcium hydroxide, sometimes called slaked or builders lime. Hydrated lime is powdery quick-acting and somewhat unpleasant to handle. The neutralizing value ranges between 120 and 135 compared to pure calcium carbonate. Fifteen hundred pounds of hydrated lime with a neutralizing value of 135 is equivalent to 2000 lbs. of agricultural lime with a neutralizing value of 100.

Marls

Marls are deposits of calcium carbonate mixed with clay and sand that are found mostly in the Coastal Plain section of the eastern states. Their neutralizing value usually ranges from 70-90 percent, dependent on the amount of impurities, mostly clay, that they contain. Their usefulness as a liming material depends on their neutralizing value and the cost of processing. They are often plastic and lumpy and must be dried and pulverized before application to the soil. Marls are usually low in magnesium. Their reaction with the soil is the same as calcitic lime.

Basic Slag

Basic slag is a product of the basic open-hearth method of making steel. The calcium contained is in the form of calcium silicate and reacts with soil acids in a manner similar to ground limestone. Its neutralizing value ranges from 60 to 70, but since it generally has smaller particles than agricultural lime, it tends to change soil pH more rapidly than conventional agricultural lime. It also contains P_2O_5 ranging from 2-6% and some micronutrients and magnesium.

Ground Oyster Shells

Oyster shells and other sea shells are largely calcium carbonate. They make a satisfactory liming material when finely ground and have a neutralizing value of 90 to 110. Since they are composed of primarily calcium carbonate, they contain little or no magnesium.

Table 4.4: Liming Materials, Chemical Composition and Calcium Carbonate Equivalent

MATERIAL	COMPOSITION	CALCIUM CARBONATE EQUIVALENT (CCE)
Calcitic Limestone	$CaCO_3$	85-100
Dolomitic Limestone	$CaCO_3$; Mg CO_3	95-108
Oyster Shells	$CaCO_3$	90-110
Marl	$CaCO_3$	50-90
Hydrated Lime	$Ca(OH)_2$	120-135
Basic Slag	$CaSiO_3$	50-70
Gypsum	$CaSO_4$	None

Fineness of Grinding is Important in Selecting Liming Materials

Lime quality is measured by how effectively it neutralizes soil acidity. This is determined largely by (1) its chemical purity and (2) size of particles.

The purity of lime is expressed as calcium carbonate equivalent (CCE). It is a measure of how much of the material can react with the soil to neutralize acidity under ideal conditions compared to pure calcium carbonate. Limestone should have a neutralizing value of at least 90%.

Even though the CCE of lime may be satisfactory, it will not neutralize soil acidity unless the limestone is finely ground. An experiment conducted by Auburn University on fineness of lime illustrates the importance of fineness of limestone in neutralizing soil acidity.

These research results indicate that limestone coarser than 10 or 20 mesh is of practically no value, even after several years. Limestone fine enough to pass a 60-mesh screen is effective in neutralizing soil acidity. The term "mesh" refers to the number of openings per square inch on a screen. A 60-mesh lime is lime that will go through a screen containing 60 openings per square inch of screen.

Effective Calcium Carbonate Content

Most liming materials are sold on the basis of their calcium carbonate equivalent which may range from 50-105 percent. One-hundred percent calcium carbonate is pure calcium carbonate. However, a liming material may be classified as 100 percent calcium carbonate equivalent and if it will not pass an 8 to 10-mesh screen, it would be ineffective as a liming material. The obvious reason is that the lime is ground too coarse and, consequently, it may require 8-10 years for the lime to become effective.

In an attempt to arrive at a more accurate lime rating to measure liming material effectiveness, some states' soil test laboratories have adopted an effective calcium carbonate content for rating liming materials. An efficiency rating is arrived at by multiplying the calcium carbonate equivalent times the effective calcium carbonate content, which is based on the fineness of the liming material.

The terms used to describe a liming material efficiency rating vary among and include "effective calcium carbonate equivalent," "relative neutralizing value," and "effective neutralizing value." While the terminology varies, the sieves used to characterize limestone fineness vary, the sieve passing percentage requirements vary, and the assigned particle size effectiveness varies among states and labs ... the general principle remains fairly similar for describing the potential effectiveness of liming materials in neutralizing soil acidity.

The following example of the "effective neutralizing value" (ENV) calculation, used by the University of Illinois, serves to illustrate the importance of lime particle size in potential soil acidity neutralization.

ENV = Total fineness efficiency x (% Calcium Carbonate Equivalent / 100)

Table 4.5: Efficiency Factors for Liming Material

Particle Size	Within 1 Year of Application	After 4 Years of Application
Greater than 8 mesh	5	15
Between 8 and 30	20	45
Between 30 and 60	50	100
Smaller than 60 mesh	100	100

EXAMPLE

Assume that a liming material has a 96 percent calcium carbonate equivalent. After screening, the liming material is found to have the following particle size distribution:

+8 mesh	=	4%
-8 to +30	=	25%
-30 to +60 mesh	=	26%
-60 mesh	=	45%

The total fineness efficiency factor may be calculated as follows for the example material:

+8 mesh efficiency is 5%, so	.04 x 5 = 0.20
-8 to 30 mesh efficiency is 20%, so	.25 x 20 = 5.00
-30 to +60 mesh efficiency is 50%, so	.26 x 50 = 13.00
-60 mesh efficiency is 100%, so	.45 x 100 = 45.00
Total Fineness Efficiency for 1st year =	63.20

Therefore, the effective calcium carbonate content of ENV = 63.20 x (96 / 100) = 60.67 for this example liming material for the first year.

If a farmer wishes to know the value of the lime the first year and also after four years, the calculation for the first year can be made as shown. Then the calculations can also be made using the factors shown above for after four years. Such calculations enable a grower to determine the shorter term and the longer term value of the liming material being considered for purchase.

Fluid Lime

A liming material commonly referred to as Fluid Lime is currently being marketed. Fluid lime generally consists of finely ground limestone suspended in water at a ratio of about 50% water to 50% limestone. In most instances, producers of fluid lime utilize very finely ground limestone — most of which will pass a 200-mesh screen. It is almost impossible to apply such finely ground limestone as a solid material because of the dust problem.

By utilizing finely ground limestone materials, fluid lime producers are making a liming material that is capable of changing soil pH in a relatively short period of time. This is a distinct advantage in situations where liming has been delayed to just before planting, or in situations where low soil pH is discovered after a crop is planted. Unfortunately, some fluid lime venders are stating that one-half ton of fluid lime is equivalent to one ton of solid agricultural lime in effectiveness. Since fluid lime contains approximately 50% water, this means that a farmer applying fluid lime at the rate of 1000 lbs. per acre would be applying only 500 lbs. of limestone. On soils with a CEC (Cation Exchange Capacity) of 5 m.e. per 100 grams or more, this amount of lime would probably not change the soil pH over 0.4 of a pH unit during the crop growing season.

Table 4.6: Results from a university greenhouse experiment measuring the effect of soil pH changes by liming materials of varying fineness of grinding

LIME EXPERIMENT, 1978 (CECIL SOIL)			
	LIME	SOIL pH CHANGE	
TREATMENT	TONS/A	10 DAYS	6 MONTHS
Check	0	5.0	4.5
Fine Lime	1	7.2	5.8
Reg. Lime	1	5.7	5.4
Fine Lime	3	7.4	7.1
Reg. Lime	3	6.8	6.6

Note: The fine lime was minus 200 mesh in particle size. The regular lime was ordinary agricultural dolomitic limestone.

Results from this experiment indicated that the finely ground limestone was much more effective in changing soil pH in a 10-day period than conventional lime. However, after a 6-month period, the soil pH changes by both lime sources were similar.

In another experiment, an attempt was made to measure soil pH changes by applications of varying amounts of finely ground and conventionally ground limestone materials. Both sources of limestone were applied at 1/8, 1/4, 1/2 and full lime requirements. Lime requirement was defined as the calculated amount of lime required to change the soil pH to 7.0.

Table 4.7: Results from a university greenhouse experiment measuring soil pH changes

LIME EXPERIMENT 1978 BLADEN SOIL, CEC 10.9 M.E., ORIGINAL SOIL pH 4.5				
	LIME	LIME APPLIED	pH CHANGE	
TREATMENT	REQUIREMENT	TONS/A	6 MONTHS	12 MONTHS
Dolomite	1/8	1.25	4.6	4.6
Fine Lime*	1/8	1.25	4.6	4.6
Dolomite	1/4	2.50	5.3	5.2
Fine Lime*	1/4	2.50	5.3	5.4
Dolomite	1/2	5.00	5.9	6.0
Fine Lime*	1/2	5.00	6.5	6.5
Dolomite	Full	10.00	6.7	6.9
Fine Lime	Full	10.00	7.1	7.1

* = Majority passing through a 200-mesh screen.

Results of this experiment indicate that applying either dolomite or fine lime at 1/4 of the lime requirement increased the soil pH approximately 0.8 of a pH unit in a six-month period.

Pelletized Lime

Pelletized lime is finely ground agricultural limestone that is pelletized with the aid of clay or synthetic binders to produce pellets in the 5 to 14-mesh range. Usually, about 70 percent of the initial limestone, prior to pelletizing, passes 100 to 200 mesh sieves. It may be spread with conventional spinner fertilizer spreaders, which makes it attractive to use. Unpublished research indicates that pelletized lime should be allowed to react with a good rainfall or irrigation on the soil surface to disperse the pellet, before it is mixed with the soil. If rates of 250 to 500 pounds of this liming material are mixed with the soil before the pellet "melts" down, a limited soil volume may be affected by each pellet and desirable pH adjustment of the plow layer may not be achieved.

The principle affecting the amount of material applied and the reaction time for pelletized lime are similar to those covered in the fluid lime section.

In summary, it appears that fluid and pelletized lime are excellent sources of lime to be used under certain circumstances such as: 1) Correction of a low soil pH condition after a crop is planted; 2) For a rapid change in soil pH if liming is delayed to just before planting a crop; or 3) For maintaining pH in the optimal range for plant growth and yield. However, these two liming materials should not be depended upon to maintain the soil pH during the full crop growing season if applied at 1/4 of the recommended lime rate.

More recent research illustrated by the following four figures supports these statements and conclusions.

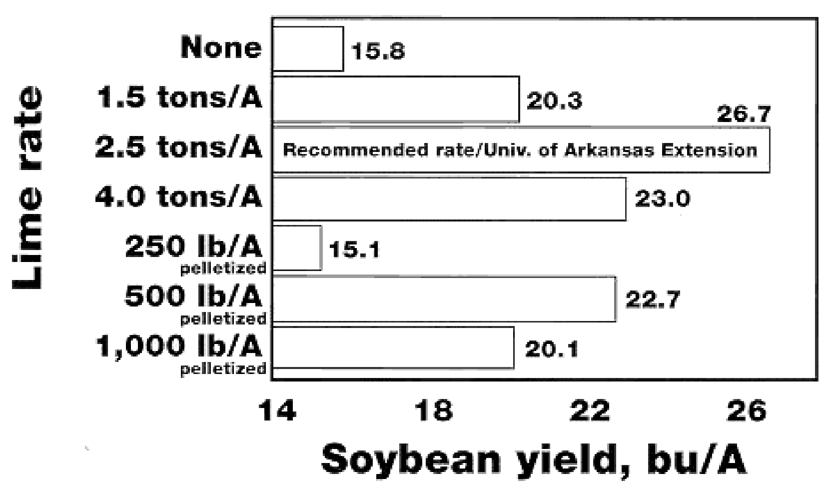

Figure 4.1 Double-cropped soybean responses to aglime and pelletized lime. Source: Muir et al., Arkansas.

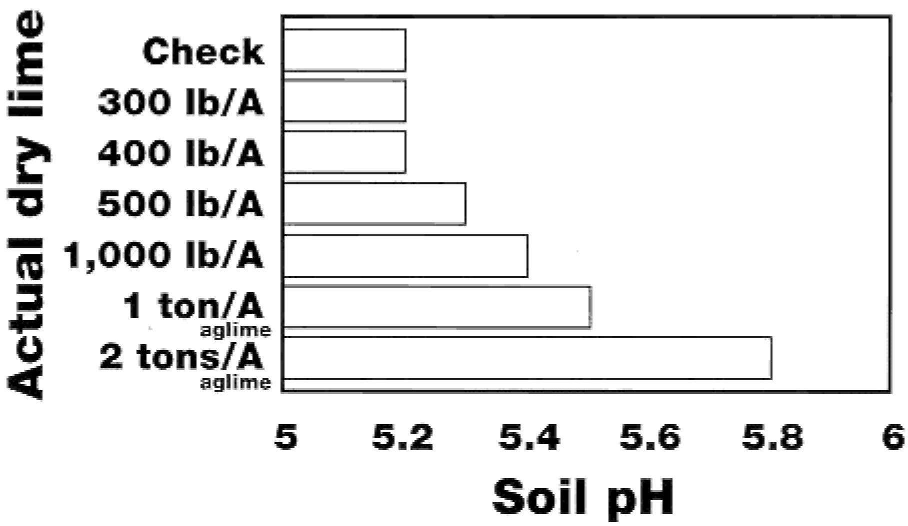

Figure 4.2 Soil pH 100 days after lime application. Source: Lessman, Tennessee.

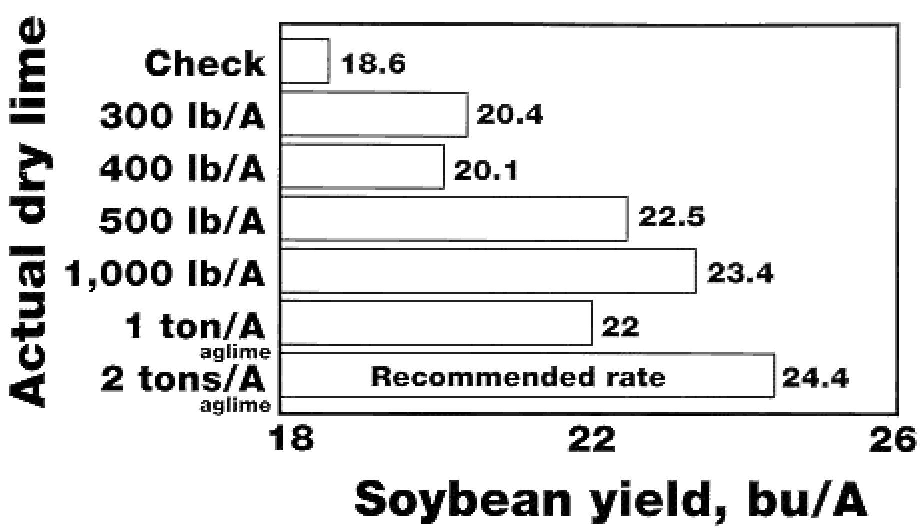

Figure 4.3 Aglime effects on soybean yields - first year. Source: Lessman, Tennessee.

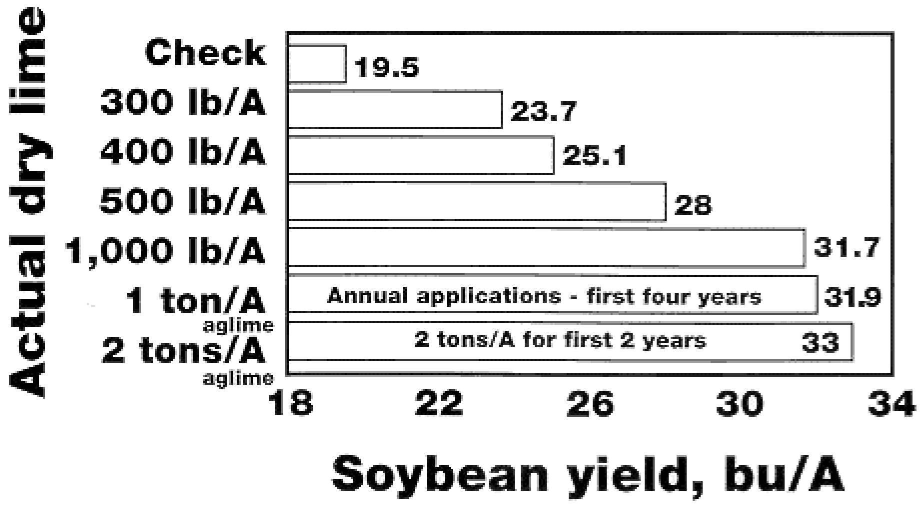

Figure 4.4 Annual aglime application effects on soybean yields - five-year average. Source: Lessman, Tennessee.

Lime Timing, Placement, and Frequency of Application

For crop rotations that include legumes like alfalfa or clovers, lime should be applied to allow enough time for reaction with the soil before the legumes are planted. Ideally, lime should be applied three to six months ahead of seeding the targeted crop. Applications as late as just before planting, with good soil incorporation, can still be beneficial on strongly acid soils. Some reduction in soil acidity will still occur, although maximum pH increases are not normally reached until about one year after application of typical agricultural limestone.

Placement is just as important as lime quality. Maximum contact with the soil is essential for neutralization of soil acidity. Most common liming materials are only sparingly soluble in water. For example, ammonium nitrate is about 84,000 times more soluble than pure calcium carbonate. Even if lime is properly mixed into the plow layer, it will have little reaction if the soil is dry. Moisture must be available for the lime-soil reaction to occur. Perhaps the best way to incorporate lime or any other material with the plow layer is to use two perpendicular passes of a combination disc, followed by a chisel plow. Deep plowing of lime does not achieve desirable mixing in the upper six to eight inches of soil. However, because the plow or a heavy breaking disc inverts the lime, it can help to distribute the lime in the upper portion of the subsoil. Choice of tillage equipment will depend on the depth at which soil acidity neutralization is most needed. Good horizontal and vertical mixing of the lime provide the best results.

In some cropping systems like established perennial sods or established no-till crop production, mixing lime with the plow layer is not possible. Lime should be incorporated to adjust the pH in the plow layer before the establishment of these cropping systems. Once the desired pH is attained, it can be maintained by surface applications in these no-tillage systems. Surface-applied lime reacts more slowly than lime which is mixed with the soil and usually only affects pH in the upper two to three inches of soil. Research at Pennsylvania State University indicated that surface applications of limestone in no-till crop production can begin to influence soil pH below the two-inch depth after the fourth year, when lime is applied about every third year. Surface liming every third year with 6,000 pounds of lime/A was just as beneficial as annual lime applications of 3,000 pounds/A.

The more intensive the crop production, the higher the nitrogen fertilizer or manure use, and the greater the crop yields (and nutrient removal), the greater and more frequent the need will be for lime. Soil sampling is the best way to evaluate soil pH levels and the need for lime.

Excess Alkalinity - Natural And Induced

Many soils in the semi-arid and arid regions of the U.S. have a naturally high pH. They may contain significant quantities of "free calcium carbonate." However, these areas are not the only ones with problems associated with high pH. Irrigation well water may contain significant quantities of calcium and/or magnesium carbonate in certain regions of the United States. In areas of the midsouth for example, some irrigation well water contains in excess of 3 to 5 milliequivalents of bicarbonate per liter and 3 to 5 milliequivalents of calcium. An acre-foot of water or more per year, can deliver more than 300 to 600 pounds of calcium and/or magnesium carbonate (lime) per acre. Sprinkler irrigation systems tend to deliver the lime in the water uniformly across the field. If "flood" or furrow irrigation systems are used, much of the lime from the water may precipitate in the upper regions of fields nearest the water delivery inlets and in the water flow path. In effect, the soil is limed by the irrigation water. If the water distribution and delivery are the same over several years, the soil may become alkaline, with soil pH levels rising to 7.0 and above. Soil pH increases may approach 0.2 pH units per year, until an equilibrium is reached with atmospheric carbon dioxide levels. Such soil pH increase will occur more rapidly on coarse and medium-textured soils than on clays which are more highly buffered.

If the well water contains significantly more sodium compared to calcium or magnesium, there may be a risk of sodium buildup on soils which do not readily leach. This is more often a greater concern in arid regions than in humid regions. Soils with naturally high sodium levels, or those which have received large quantities of sodium bicarbonate through irrigation, may have pH levels as great as 8.5, or higher. Theoretically, if sodium is not a factor, even if large quantities of calcium or magnesium carbonate are applied, the soil pH will not exceed 8.2 to 8.3. At pH 8.2, the soil carbonate reaches an equilibrium with the carbon dioxide level in the atmosphere.

If irrigation water is suspected or known to deliver significant amounts of lime salts and/or soluble salts, soil samples should be collected more frequently to better monitor soil pH, salinity, and cation balance. Irrigation water quality should also be periodically monitored.

Correction of Excess Alkalinity by Soil Acidulation

Elemental sulfur may be used to acidify alkaline soil to the desirable pH range. It may also be used to maintain pH in the desirable range, on soils which tend to become alkaline with management. When elemental sulfur is applied to soil it combines with oxygen and water to form sulfuric acid. This oxidation of sulfur is brought about by certain microorganisms and may take from three to six weeks or longer, depending on the soil conditions. The finer the sulfur is ground, the more rapid is the conversion to sulfate and dilute sulfuric acid. The rate of decrease in pH with elemental sulfur may be similar to the rate of pH increase brought about by liming. The more free calcium carbonate present and the more buffered the soil, the longer it will take to acidify the soil. More sulfur will also be needed on soils with free carbonates present. The approximate amounts of elemental sulfur (99% S) needed to reduce soil pH for different soils, which have no free carbonate, are shown in Table 4.8.

Table 4.8: Approximate Amount of Elemental Sulfur Needed to Increase Acidity (reduce pH) of a Carbonate-Free Soil

Change in pH Desired	Sand	Soil Texture Silt Loam	Clay
	------Pounds of Sulfur per Acre------		
8.5 to 6.5	2000	2500	3000
8.0 to 6.5	1200	1500	2000
7.5 to 6.5	500	800	1000
7.0 to 6.5	100	150	300

NOTE: If free carbonates are present, higher rates than those shown will be required Reference: Western Fertilizer Handbook, eighth edition. California Fertilizer Association

Aluminum sulfate is another amendment often used in ornamental horticulture to acidify soil in plant beds. However, more of it is needed to produce the same acidification as elemental sulfur, even though it offers the advantage of a faster reaction. Compared to elemental sulfur, the rate may need to be two to seven times greater. Little of this amendment is used in commercial agriculture.

Lime Tables

Figure 4.5 Midwest U.S. Lime Recommendations, Lime to Give pH 6.4 (138k)

Lime Table 1

MIDWEST U.S. LIME RECOMMENDATIONS

Soil-Water pH	Soil Buffer pH															If Buffer pH is Missing
	5.5	5.6	5.7	5.8	5.9	6.0	6.1	6.2	6.3	6.4	6.5	6.6	6.7	6.8	6.9	
	Lime (Tons/Acre) to Give pH 6.4*															
4.5	7.0	7.0	6.0	6.0	6.0	5.0	5.0	4.0	4.0	4.0	4.0	4.0	3.0	3.0	3.0	4.0
4.6	7.0	7.0	6.0	6.0	6.0	5.0	5.0	4.0	4.0	4.0	4.0	4.0	3.0	3.0	3.0	4.0
4.7	7.0	7.0	6.0	6.0	6.0	5.0	5.0	4.0	4.0	4.0	4.0	4.0	3.0	3.0	3.0	4.0
4.8	7.0	7.0	6.0	6.0	6.0	5.0	5.0	4.0	4.0	4.0	4.0	4.0	3.0	3.0	3.0	4.0
4.9	7.0	7.0	6.0	6.0	6.0	5.0	5.0	4.0	4.0	4.0	4.0	3.0	3.0	3.0	3.0	4.0
5.0	7.0	6.0	6.0	6.0	5.0	5.0	5.0	4.0	4.0	4.0	3.0	3.0	3.0	2.0	2.0	3.5
5.1	7.0	6.0	6.0	6.0	5.0	5.0	5.0	4.0	4.0	4.0	3.0	3.0	3.0	2.0	2.0	3.5
5.2	7.0	6.0	6.0	6.0	5.0	5.0	5.0	4.0	4.0	4.0	3.0	3.0	3.0	2.0	2.0	3.5
5.3	7.0	6.0	6.0	5.0	5.0	5.0	4.0	4.0	4.0	3.0	3.0	3.0	3.0	2.0	2.0	3.0
5.4	6.0	6.0	5.0	5.0	5.0	5.0	4.0	4.0	4.0	3.0	3.0	3.0	2.0	2.0	2.0	3.0
5.5	6.0	6.0	5.0	5.0	5.0	4.0	4.0	4.0	4.0	3.0	3.0	3.0	2.0	2.0	2.0	3.0
5.6	6.0	6.0	5.0	5.0	4.0	4.0	4.0	4.0	3.0	3.0	3.0	3.0	2.0	2.0	2.0	2.5
5.7	6.0	6.0	5.0	5.0	4.0	4.0	4.0	3.0	3.0	3.0	3.0	2.0	2.0	2.0	1.0	2.5
5.8	----	5.0	5.0	5.0	4.0	4.0	4.0	3.0	3.0	3.0	2.0	2.0	2.0	2.0	1.0	2.5
5.9	----	----	5.0	4.0	4.0	4.0	3.0	3.0	3.0	2.0	2.0	2.0	2.0	2.0	1.0	2.0
6.0	----	----	----	4.0	3.0	3.0	3.0	3.0	2.0	2.0	2.0	2.0	2.0	1.0	1.0	2.0
6.1	----	----	----	----	3.0	3.0	3.0	2.0	2.0	2.0	2.0	1.0	1.0	1.0	1.0	1.5
6.2	----	----	----	----	----	3.0	2.0	2.0	2.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
6.3	----	----	----	----	----	----	2.0	2.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
6.4	----	----	----	----	----	----	----	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
6.5	----	----	----	----	----	----	----	----	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
6.6	----	----	----	----	----	----	----	----	----	0.0	0.0	0.0	0.0	0.0	0.0	
6.7	----	----	----	----	----	----	----	----	----	----	0.0	0.0	0.0	0.0	0.0	
6.8	----	----	----	----	----	----	----	----	----	----	----	0.0	0.0	0.0	0.0	
6.9	----	----	----	----	----	----	----	----	----	----	----	----	0.0	0.0	0.0	
7.0	----	----	----	----	----	----	----	----	----	----	----	----	----	0.0	0.0	

*Based on Relative Neutralizing Value of Ag Lime = 67%. Tillage depth = 6 to 8 inches

Source: University of Kentucky, Division of Regulatory Service

NOTE: Based on soil pH and "SMP" (Shoemaker-McLean-Pratt) buffer pH. No recommendations are shown when Buffer pH is more than 0.2 units below water pH because that condition usually means a definite error in one of the pH readings.

Figure 4.6 Midwest U.S. Lime Recommendations, Lime to Give pH 6.6 (135k)

Lime Table 2

MIDWEST U.S. LIME RECOMMENDATIONS

Soil-Water pH	Soil Buffer pH 5.5	5.6	5.7	5.8	5.9	6.0	6.1	6.2	6.3	6.4	6.5	6.6	6.7	6.8	6.9	If Buffer pH is Missing
	Lime (Tons/Acre) to Give pH 6.6*															
4.5	7.0	7.0	7.0	7.0	6.0	6.0	6.0	5.0	5.0	5.0	4.0	4.0	4.0	3.0	3.0	4.5
4.6	7.0	7.0	7.0	7.0	6.0	6.0	6.0	5.0	5.0	5.0	4.0	4.0	4.0	3.0	3.0	4.5
4.7	7.0	7.0	7.0	7.0	6.0	6.0	6.0	5.0	5.0	5.0	4.0	4.0	4.0	3.0	3.0	4.5
4.8	7.0	7.0	7.0	7.0	6.0	6.0	6.0	5.0	5.0	5.0	4.0	4.0	4.0	3.0	3.0	4.5
4.9	7.0	7.0	7.0	7.0	6.0	6.0	6.0	5.0	5.0	5.0	4.0	4.0	4.0	3.0	3.0	4.5
5.0	7.0	7.0	7.0	7.0	6.0	6.0	5.0	5.0	5.0	4.0	4.0	4.0	4.0	3.0	3.0	4.0
5.1	7.0	7.0	7.0	7.0	6.0	6.0	5.0	5.0	4.0	4.0	4.0	4.0	4.0	3.0	3.0	4.0
5.2	7.0	7.0	7.0	7.0	6.0	5.0	5.0	5.0	4.0	4.0	4.0	4.0	3.0	3.0	3.0	4.0
5.3	7.0	7.0	7.0	7.0	6.0	5.0	5.0	5.0	4.0	4.0	4.0	4.0	3.0	3.0	2.0	3.5
5.4	7.0	7.0	7.0	6.0	6.0	5.0	5.0	5.0	4.0	4.0	3.0	3.0	3.0	2.0	2.0	3.5
5.5	7.0	7.0	6.0	6.0	5.0	5.0	5.0	4.0	4.0	4.0	3.0	3.0	3.0	2.0	2.0	3.5
5.6	6.0	6.0	6.0	6.0	5.0	5.0	4.0	4.0	4.0	4.0	3.0	3.0	3.0	2.0	2.0	3.0
5.7	6.0	6.0	6.0	5.0	5.0	5.0	4.0	4.0	4.0	3.0	3.0	3.0	2.0	2.0	2.0	3.0
5.8	----	6.0	5.0	5.0	5.0	4.0	4.0	4.0	4.0	3.0	3.0	3.0	2.0	2.0	2.0	3.0
5.9	----	----	5.0	5.0	4.0	4.0	4.0	3.0	3.0	3.0	3.0	3.0	2.0	2.0	2.0	2.5
6.0	----	----	----	4.0	4.0	4.0	3.0	3.0	3.0	3.0	2.0	2.0	2.0	2.0	1.0	2.5
6.1	----	----	----	----	4.0	3.0	3.0	3.0	3.0	2.0	2.0	2.0	2.0	2.0	1.0	2.0
6.2	----	----	----	----	----	3.0	3.0	3.0	2.0	2.0	2.0	2.0	2.0	1.0	1.0	2.0
6.3	----	----	----	----	----	----	3.0	2.0	2.0	2.0	2.0	1.0	1.0	1.0	1.0	1.5
6.4	----	----	----	----	----	----	----	2.0	2.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
6.5	----	----	----	----	----	----	----	----	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
6.6	----	----	----	----	----	----	----	----	----	0.0	0.0	0.0	0.0	0.0	0.0	
6.7	----	----	----	----	----	----	----	----	----	----	0.0	0.0	0.0	0.0	0.0	
6.8	----	----	----	----	----	----	----	----	----	----	----	0.0	0.0	0.0	0.0	
6.9	----	----	----	----	----	----	----	----	----	----	----	----	0.0	0.0	0.0	
7.0	----	----	----	----	----	----	----	----	----	----	----	----	----	0.0	0.0	

*Based on Relative Neutralizing Value of Ag Lime = 67%. Tillage depth = 6 to 8 inches

Source: University of Kentucky, Division of Regulatory Service

NOTE: Based on soil pH and "SMP" (Shoemaker-McLean-Pratt) buffer pH. No recommendations are shown when Buffer pH is more than 0.2 units below water pH because that condition usually means a definite error in one of the pH readings.

Figure 4.7 Southeast U.S. Lime Recommendations, Lime to Give pH 6.5 (106k)

Lime Table 3

SOUTHEAST U.S. LIME RECOMMENDATIONS

Soil-Water pH	5.9	5.8	5.7	5.6	5.5	5.4	5.3	5.2	5.1	5.0	4.9	4.8	4.7	4.6	4.5	4.4	Tons/A
Soil-Buffer pH	Hundreds of pounds ag lime per acre to give pH 6.5[1]																
7.90	6	6	7	8	8	9	9	9	10	10	10	11	11	11	12	12	1.0
7.85	9	10	11	11	12	13	13	14	15	15	16	16	17	17	18	19	
7.80	12	13	14	15	16	17	18	19	20	20	21	22	22	23	24	25	1.5
7.75	15	16	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
7.70	17	19	21	23	24	26	27	28	29	30	31	32	33	34	36	38	2.0
7.65	20	23	25	27	28	30	31	33	34	35	37	38	39	40	42	44	
7.60	23	26	28	30	32	34	36	37	39	40	42	43	45	46	48	50	2.5
7.55	26	29	32	34	36	38	40	42	44	46	47	49	50	52	53	56	3.0
7.50	29	32	35	38	40	43	45	47	49	51	52	54	56	57	59	63	
7.45	32	36	39	42	44	47	49	52	54	56	58	59	61	63	65	69	3.5
7.40	35	39	42	46	48	51	54	56	59	61	63	65	67	69	71	75	4.0
7.35	38	42	46	49	53	56	58	61	63	66	68	70	72	75	77	81	
7.30	41	45	49	53	57	60	63	66	68	71	73	76	78	80	83	88	
7.25	44	48	53	57	61	64	67	70	73	76	78	81	84	86	89	94	
7.20	47	52	56	61	65	68	72	75	78	81	84	86	89	92	95	100	
7.15	49	55	60	64	69	73	76	80	83	86	89	92	95	98	101	106	
7.10	52	58	63	68	73	77	81	84	88	91	94	97	100	103	107	113	
7.05	55	61	67	72	77	81	85	89	93	96	99	103	106	109	113	119	
7.00	58	65	71	76	81	85	90	94	98	101	105	108	111	115	119	125	

[1]Based on Relative Neutralizing Value of Ag Lime = 67%. Tillage depth = 8 inches

Figure 4.8 Southeast U.S. Lime Recommendations, Lime to Give pH 6.0 (107k)

Lime Table 4

SOUTHEAST U.S. LIME RECOMMENDATIONS

Soil-Water pH	5.9	5.8	5.7	5.6	5.5	5.4	5.3	5.2	5.1	5.0	4.9	4.8	4.7	4.6	4.5	4.4	Tons/A
Soil-Buffer pH	Hundreds of pounds ag lime per acre to give pH 6.0[1]																
7.90	1	2	3	4	4	5	6	6	7	7	8	8	9	9	10	11	1.0
7.85	2	3	4	5	7	8	9	9	10	11	12	13	13	14	15	16	
7.80	2	4	6	7	9	10	11	13	14	15	16	17	18	19	20	22	
7.75	3	5	7	9	11	13	14	16	17	18	20	21	22	23	25	27	1.5
7.70	3	6	9	11	13	15	17	19	20	22	24	25	27	28	30	33	
7.65	4	7	10	13	15	18	20	22	24	26	28	29	31	33	35	38	2.0
7.60	4	8	11	15	17	20	23	25	27	29	31	33	35	38	40	43	
7.55	5	9	13	16	20	23	26	28	31	33	35	38	40	42	45	49	2.5
7.50	5	10	14	18	22	25	28	31	34	37	39	42	44	47	50	54	
7.45	6	11	16	20	24	28	31	34	38	40	43	46	49	52	55	60	3.0
7.40	6	12	17	22	26	30	34	38	41	44	47	50	53	56	60	65	3.5
7.35	7	13	19	24	28	33	37	41	44	48	51	54	58	61	65	71	
7.30	7	14	20	25	35	31	40	44	48	51	55	59	62	66	70	76	4.0
7.25	8	15	21	27	33	38	43	47	51	55	59	63	67	70	75	81	
7.20	8	16	23	29	35	40	45	50	55	59	63	67	71	75	80	87	
7.15	9	17	24	31	37	43	48	53	58	62	67	71	75	80	85	92	
7.10	9	18	26	33	39	45	51	56	61	66	71	75	80	84	90	98	
7.05	10	19	27	35	41	48	54	59	65	70	75	79	84	89	94	103	
7.00	10	20	28	36	44	50	57	63	68	74	79	84	89	94	99	109	

[1] Based on Relative Neutralizing Value of Ag Lime = 67%. Tillage depth = 8 inches

NOTE: Source: Alabama Agricultural Experiment Station, Auburn University. Based on soil pH and the "Adams-Evans" buffer pH.

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