Soil Acidity and Liming of Indiana Soils
AY-267

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Most Indiana soils require periodic applications of limestone or other liming materials for optimum crop production. Liming has several beneficial effects: 1) it reduces harmful acidic conditions which develop in soils and that limit the availability of some nutrients but increase toxicity of others; 2) it replaces the supply of calcium and magnesium essential for plant growth; 3) it ensures favorable conditions for effective activity of certain herbicides; and 4) it provides a suitable environment for organic materials to decompose and enhance good soil structure and tilth.

Causes or Sources of Acidity

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

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 grown, b) part of crop harvested, and c) stage of growth at harvest. Removal is greater for hay 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
Hay Crops	**ton/a**		**-- lb/a --**	
Alfalfa	6	180	28	240
Red clover	3	75	22	100
Grass	3	22	10	110
Grain crops	**bu/a**			
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 other fertilizers. Two processes are involved. First, commonly used nitrogen fertilizers contain ammonium nitrogen (urea is an ammonium forming material). Soil bacteria convert ammonium (NH_4^+) to nitrate (NO_3^+) through a biochemical process called nitrification. Hydrogen (H^+) is released in this process, and free hydrogen ions cause an increase in acidity. The second acidifying effect 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 may be carried below the root zone. They take with them other nutrients that have a positive charge-most likely calcium and magnesium-and their removal in this manner has the same acidifying effect on soils as removal by a crop.

Table 2 shows the calculated amount of typical aglime needed to offset the acidity potential of common nitrogen 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 and can be a pollution hazard.

Table 2. Amount of aglime required to neutralize acidity created by nitrogen fertilizer.

Fertilizer	N Conc.	Aglime* needed per 100 lb. actual N
	%	**lb.**
Ammonium nitrate	34	225
urea	46	225
Anhydrous ammonia	82	225
urea-ammonium nitrate solutions	28-32	225
Ammonium sulfate	21	669

*Aglime with a CCE of 80% (Source: NSA Aglime Fact Book)

Rainfall. Soils can become acid even in the absence of crop removal or fertilizer applications. Rainfall is considered a natural cause of acidity because of the downward movement of water through the soil profile and the removal of nutrients from surface runoff and erosion.

Indiana is located in a humid area where rainfall exceeds the amount of water use by plants. As water moves down through the soil profile, it has a slow but persistent acidifying affect. Weak acids (corresponding 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. potassium, and sodium as the soil solution (water) moves down through and below the root zone (leaching). Hydrogen, or aluminum if soil pH is less than 5.2, replace basic cations causing the soil in the leached zone to become more acid.

Examples of this process are found in south central Indiana soils where limestone rock is found just a few feet below an acid surface soil. In some cases, sinkholes" have developed where sufficient limestone dissolved in this process and caused a collapse of the surface soil. Surface runoff can carry calcium, magnesium, and other nutrients in solution. Likewise, these nutrients can be physically removed in the erosion process. Both actions leave the remaining soil more acid.

Acid rain receives considerable publicity but is not a significant factor in a farmer's liming program. The present day acid rain of Indiana has a pH of about 4.3. This acid is produced by the sulfur (S) and nitrogen (N) oxides in the air reacting with water; it amounts to less than a half pound (0.5 lb.) of acid (H^+) per acre in a year's rain. There may be another 0.5 lb. of acid added by dry deposition which is the dust of S and N compounds from the air. Thus, up to 1 lb. total of acid (H^+) per acre per year may be deposited on Indiana land. Neutralizing this requires a total of about 50 lb. of limestone per acre per year. Thus, a ton of lime every forty or fifty years neutralizes the effect of acid rain.

Note that this same N and S in Indiana rain and dry deposition, which produces the acidity, also supplies about 10 lbs. of N and 15-20 lbs. of S fertilization per acre per year as a positive bonus.

Measuring Acidity

Soil testing laboratories add distilled water to dry soils in a small paper cup, mix them together and then use an instrument called a pH meter to determine if a soil is acid or not. The pH meter has been calibrated (adjusted) to give a reading of 7 (pH 7) in distilled water which has an equal number of free hydrogen (H^+) acidic ions and hydroxyl (OH^-) basic ions. Therefore a pH of 7.0 is neutral (equal). If the pH meter reads less than 7.0, there are more acidic ions than basic ions and the solution. or soil, is classed as acidic.

Likewise if readings are above 7.0. there are fewer acid ions than basic ions and the soil is considered basic.

It is important to recognize that pH readings are logarithmic. As an example, a soil with a pH of 5.0 is *10 times* as acid than one with a pH of 6.0 and *100 times* more acid than one with pH 7.0.

Soil pH vs. Lime index. The initial determination of a limestone recommendation for field crops at the Purdue Soil and Plant Analysis Laboratory is a two step process. First, a soil-water mixture pH is measured. If the soil pH (also called water pH) value is 6.0 or above (6.6 or above for alfalfa, sweet clover, and birdsfoot trefoil), there is no need to add a liming material for field crops When the soil pH is below 6.6, a second test is used to determine how much limestone is needed to bring the soil pH up to a desired level for the specific crops which will be grown.

The acidity measured in a soil and water mixture is designated as active acidity and is a measure of the pH environment of the root. This does not represent the total amount of acid in a soil. Soils have a large reserve supply of acidity held by clay and organic matter particles or in aluminum and iron compounds. As calcium and magnesium carbonates from aglime neutralize the active acidity in the soil solution, more acidity is released into solution from the reserve supply and the pH does not rise. This resistance to a pH change is called buffering. Buffering capacity of a soil is a function of the clay and organic matter content as well as the amount of aluminum and iron compounds. Soils that are highly buffered require more lime to raise the pH because they have a larger supply of reserve acidity that must be neutralized.

In most laboratories, the buffering capacity (total acidity) is determined by mixing a special solution (buffer solution) with soils and measuring the change in pH. On the Purdue Soil Test Report, this test is labeled "Lime Index" (also called "SMP Buffer pH"). Lime requirements are calculated on the basis of change in pH of the buffer solution.

Beneficial Effects from Liming

Soil acidity has a direct effect upon availability of most essential plant nutrients. Figure 1 shows the general effect of pH on plant nutrient availability. The best pH range for most nutrients is between 6.0 and 7.0. Deficiencies can be observed at both low and high pH's. Manganese and iron exhibit toxicity at low pH's and deficiency at high pH levels. Although aluminum is not an essential nutrient, it is important because it rapidly increases in solubility as the soil pH drops below 5.0. Too much aluminum in solution will restrict root and plant development.

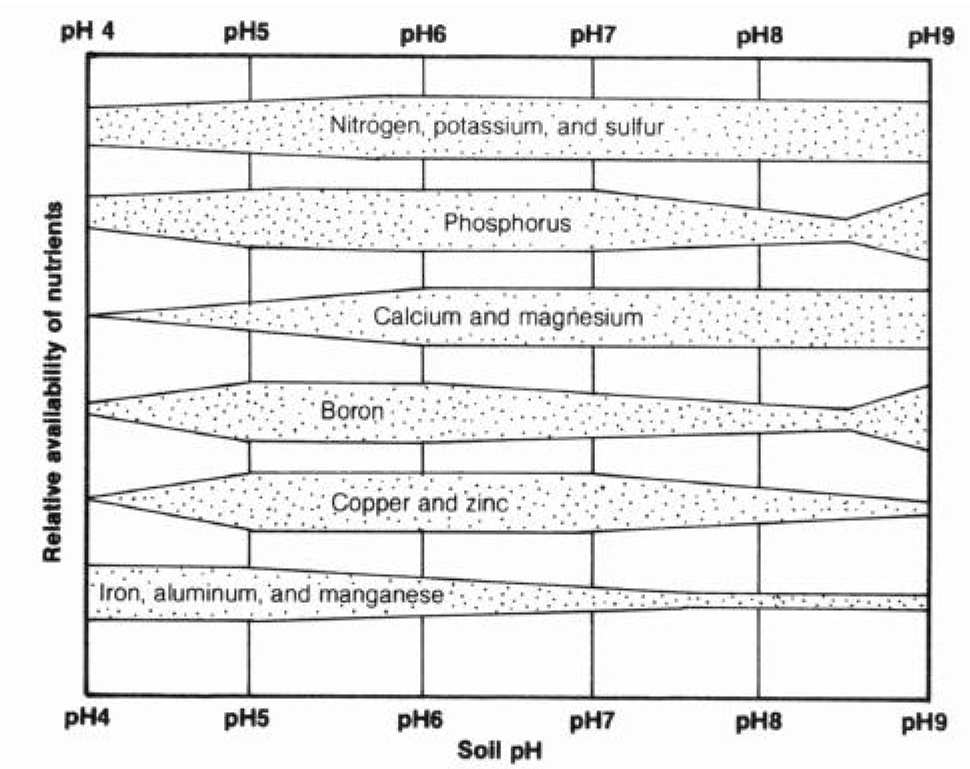

Figure 1. Effects of change in soil pH on the availability of plant nutrients.

Soil microorganisms do not function effectively in acid soils. As soil pH levels decline so does the activity of the organisms which break down (decompose) organic matter, releasing nutrients to plants. Although these organisms function best at soil pH levels of 8.0, their effectiveness does not drop rapidly until pH levels drop below 6.0. Decomposition of organic matter also contributes to aggregation (clumping) of soil particles which provides for good soil tilth, aeration, and drainage.

Effectiveness of the bacteria which enter legume roots and fix nitrogen (nodulation) is highest at pH levels of 6.5 to 7.0 and declines rapidly when pH levels fall under 6.0.

Some herbicides, particularly triazines, lose some of their effectiveness in soils that have pH levels under 6.0. The problem is found most often where nitrogen has been broadcast on the surface in continuous no-till corn. A shallow acid layer develops at the soil surface and reduces the activity of the sprayed-on herbicide. Where this practice is followed, a shallow soil sample (0-2 inches) should be taken for determination of lime needs.

Crop Needs

Normal crop growth occurs over a range in pH values and the range varies by crop as shown In Figure 2. In a soil testing laboratory, the necessity for limestone is based on crops to be grown, soil pH, and soil organic matter (mineral soil vs. organic soil). The goal of a liming program is to apply enough aglime to raise the soil pH to the middle of the range for normal growth and then reapply when it drops below the range.

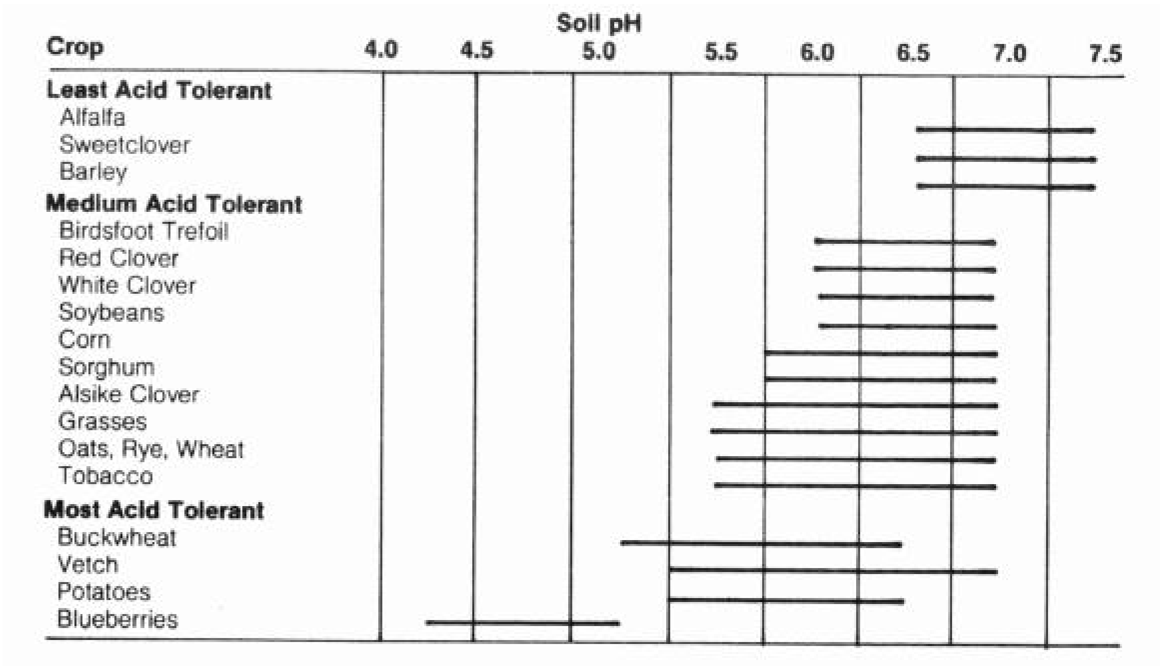

Figure 2. Mineral soil pH ranges for crops.

Soil Sampling for Limestone Needs

Many fields vary in organic matter content. This has a big influence on soil pH and lime requirement. It is important that soil samples be taken to select and identify variations that exist in a field rather than mix everything together into one sample and then obtain an average. This process requires several Samples from each field. Each sample should represent no more than 20 acres.

A detailed Soil Survey is available in most Indiana counties and provides a helpful guide to soil differences that can be expected in a field. Copies are available in SCS and County Extension offices. Out in the field, soil samples should be separated primarily on the basis of soil color differences (light vs. dark) which reflect variations in organic matter

Separate soil samples should be taken also where the texture (clay content) of soil surface varies widely. This is not a widespread problem in Indiana because about 85% of the surface soil has a silt loam texture.

Samples need to be taken at different depths with different tillage systems. If a mold board plow is used once every four or five years, take samples to plow depth. If a chisel is used as the only deep tillage tool, take samples to one half the depth that the chisel is set in the chiseling operation. Most of the soil mixing occurs in the upper one half of the chisel depth. Where fields are in continuous no-till for four years, or more, and nitrogen for corn is broadcast or sprayed on the surface, take samples from the top two to four inches to pick up the acidity developing from the nitrogen fertilizer. An adjustment in limestone recommendations will be necessary when no-till fields are sampled in this manner.

Soil pH's in the plow layer fluctuate during the growing season according to soil moisture levels. The buffer pH (Lime Index) remains more constant. As soils dry out, the pH drops due to salt accumulation near the surface of the soils. They may rise after a rain moves the salt downward into the soils. It is recommended that fields be sampled in the fall after harvest when soil moisture levels are most likely to be similar from year to year.

Liming Sources

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

Ground Aglime (Dry). 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 state, being easy to transport and apply. The calcium in limestone is in the carbonate form and most Indiana limestone also contains magnesium carbonate. Calcium content ranges from 15 to 40% and magnesium ranges from 0 to 15%. Limestone with less than 5% magnesium is designated as "calcitic limestone." It is designated as "dolomitic limestone" when the magnesium level is above 5% (pure magnesium carbonate is known as dolomite).

Factors affecting the quality of aglime are discussed in the section titled, Quality of Liming Materials.

Fluid Lime. In recent years a product called "Fluid Lime" or "Liquid Lime" has been marketed in some localities. 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 either water or liquid nitrogen fertilizer along with a suspending agent (attapulgite clay) and applying the material with a liquid fertilizer applicator. Aglime content of the product may range from 50-70%.

Two main advantages for liquid lime are:

- 1) a more uniform application can be made with the material in suspension and,
- 2) lime and nitrogen fertilization can be combined in one application trip.

Claims are also made that liquid lime will raise the soil pH faster than standard dry aglime and that much less is needed because it is ground very fine. Both statements are only partially true. For the first few months after application, the soil pH will rise faster where liquid lime is used, but within one year soil pH changes will be equal for liquid and dry material applied at equal rates. Research comparing the lasting effect of the two products is lacking.

Particles that pass a 60-mesh sieve are considered to be 100% available and effective in changing the soil pH within a year after application. Grinding particles finer than 60-mesh doesn't make them more available, so rate adjustments between materials should be based primarily on percentage of material passing a 60-mesh sieve. Limited research on fineness and rate comparisons indicate that rates for fine lime should not be reduced more than one-third to one-half of those for standard dry aglime.

Higher cost is the main disadvantage of liquid lime which is a result of the added expense in grinding the aglime fine enough to keep it in suspension and transportation costs for water if that is the liquid in which the fine aglime is suspended. Transportation costs are primarily on a weight basis and if water composes 50% of the total weight, transportation costs would be substantial.

A common application rate is 1000 pounds per acre-500 pounds of aglime and 500 pounds of water. This rate would be adequate for a maintenance program to offset acidity caused by N fertilization, but could not be used as a corrective remedy where the limestone recommendation is of 2 tons/a or more.

Pelletized Lime (Granular Lime). To avoid the dust problems associated with very fine particles, aglime and other lime (calcium) products can be compressed between heavy steel rollers into pellets or granules. Another process is to make slurry of finely ground ag lime, binding additive, and water and to granulate the aglime with the binding agent. The product can then be applied similar to dry granular fertilizer.

Pellets are readily dispersible in water and like liquid lime, will react quickly in the soil. Also, rates could be reduced from standard aglime by one-third to one-half because of the fineness of the particles being compressed together. Claims that a few hundred pounds will substitute for a ton or more of aglime cannot be substantiated by reliable research. Likewise, the practice of banding 200 to 400 pounds per acre of pelletized lime in the row as a starter fertilizer would have only limited temporary benefits early in the growing season, and any yield increase would not likely pay for the cost of the materials.

Marl. This liming material is a natural earthy material made up of marine animal shell fragments and calcium carbonate deposited in swampy areas. It also contains some clay and organic matter as impurities and is mined wet and sold by the cubic yard because of the moisture content. As a general rule two cubic yards are considered equal to one ton of aglime.

Uniform spreading is difficult unless the material is dried and ground. This practice increases its costs. Use is usually confined to localities near deposits. Since marl contains no magnesium, repeated applications may result in soils becoming deficient in magnesium. Deficiencies can be prevented by occasional reliming with dolomitic limestone.

Lime Sludges. Some water softening plants have a soft lime sludge containing fine lime particles that are precipitated in the softening process. Lime sludges vary in calcium carbonate equivalent (CCE) and water content both of which would influence the amount of sludge needed to equal dry aglime. Since the particles are small, it reacts quickly in soils similar to liquid aglime.

Fluid-bed Ash, Fly Ash, and Stack Dust. Electrical utilities sometimes mix limestone into ground coal in a fluidizing bed to control burning rates for the coal. The ash remaining after burning the coal has a neutralizing value for correcting soil acidity. Ashes and dusts collected from smoke-stacks also can neutralize soil acidity. The calcium carbonate equivalence can vary widely in the fluid-bed ash, fly ash, and stack dusts and should be determined by laboratory analysis. Application rates need to be adjusted for the relative neutralizing value of these materials.

Agricultural Slags. One of the steel industry by-products is a magnesium silicate or slag. Air-cooled slag must be ground the same as limestone. Water-cooled slag is a porous granular material produced when water is applied to the hot slag. Usually it requires screening before being sold for agricultural purposes.

Burned Lime (Quicklime). Limestone rock is heated at high temperatures to drive off carbon dioxide. It is fast acting but is corrosive, disagreeable to handle and more expensive than aglime. It is usually used in special nonagricultural situations.

Slacked Lime (Hydrated Lime). It is produced by adding water to burned lime or by absorption of moisture from the air. It has the same characteristics and limitations as burned lime.

Gypsum. This is not a liming material but is a neutral salt of calcium sulfate and will not change the soil pH. Even though it is a source of readily available calcium, a deficiency of calcium has not been detected on general field crop production in Indiana except around oil drilling operations.

Factors Affecting Recommendations and Application Rates

Recommended limestone rates that appear on soil test reports are based upon the amount required to raise the soil pH to a specific level. Soil classification as mineral or organic and crops to be grown are the two criteria used by the Purdue Soil Testing Laboratory for determining the desired soil pH level as shown on Table 3. Information is also provided in the report for making adjustments in application rates depming material being applied and depth of tillage.

Table 3. Recommended rates of limestone for field crops.

	Mineral Soils (Less than 20% OM)			Organic Soils (More than 20% OM)
	Corn, Soybeans, Small Grains, Forage Grasses most clovers[1] No lime needed if soil pH 6.0 or above)		Alfalfa, Sweetclover, Birdsfoot trefoil (No lime needed if soil pH 6.6 or above)	Most Crops[2] (No lime needed if soil pH 5.4 or above)
Lime Index (SMP Buffer pH)	Soil pH 5.8 or 5.9 Tons/A	Soil pH 5.7 or less Tons/A	Soil pH 6.5 or less Tons/A	Soil pH 5.3 or less Tons/A
7.1+	0	1	2	0
7.0	0	2	2	0
6.9	1	2	2	2
6.8	2	2	3	2
6.7	3	3	4	3
6.6	3	4	5	3
6.5	3	6	8	4
6.4	4	7	8	5
6.3	4	7	8	7
6.2 and below	4	7	8	8

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[1] Includes corn silage, popcorn, grain sorghum, sorghum silage. sorghum-sudan grass silage, oats, barley, rye, orchardgrass, sudangrass, bromegrass, tall fescue, red clover, mammoth clover, ladino clover, alsike clover, hairy vetch, crownvetch.

[2]For alfalfa, birdsfoot trefoil, sweetclover, add 2 T/A it soil pH is between 5.3 end 65

Soil. Two classifications are used: 1) mineral soils with less than 20% organic matter, and 2) organic soil if organic matter is above 20%. Due to the very high cation exchange capacity of organic matter, there are no pH related problems until soil pH drops below 5.4 on organic soils.

Crops. Agronomic crops are also separated into two categories: 1) Least acid-tolerant including alfalfa, sweetclover, and birdsfoot trefoil, and 2) less acid-sensitive all other crops as shown in Figure 2. Limestone recommendations are made separately for turf, lawns, gardens, shrubs, and horticulture crops.

Quality of Liming Materials

How effective a liming material will be in correcting soil acidity is dependent upon two factors--purity and fineness.

Purity. Liming materials vary in their composition and thus also in their capacity to neutralize acidity. Calcium carbonate equivalence (CCE) is the standard for measuring purity. Pure calcium carbonate tests 100% and magnesium carbonate has a CCE of 108 while the CCE of a product such as hydrated lime ranges between 120 and 136. Most aglime contains both calcium and magnesium carbonates along with various impurities. The CCE of Indiana limestone generally ranges between 85 and 107. A suggested minimum is a CCE of 80.

Fineness. This refers to particle size and is important because it governs how quickly acidity will be corrected. Most liming materials contain particles that vary greatly in size from dust to gravel-like particles. Small particles dissolve rapidly and react chemically with the soil to reduce acidity whereas coarse particles react very slowly and are of little value in correcting an acidity problem.

Fineness of aglime is determined by passing the material over a set of sieves (screens) of different sizes. Sieve size is expressed in terms of openings per linear inch, an 8 mesh sieve has 8 openings per inch (64 per sq. in.). Table 4 shows the relative effectiveness of different size particles. In Indiana, 8 and 60 mesh sieves are used to determine fineness. In the absence of a lime law it is suggested that a minimum of 80% pass the 8 mesh sieve and 25% pass the 60 mesh sieve.

Table 4. Relative effectiveness of different size limestone particles.

Particle Size	Percent Available In 3 Years
Larger than 8 mesh	0-10
Pass 8 mesh, held on 60 mesh	40-50
Smaller than 60 mesh	90-100

The ultimate effectiveness (quality) of aglime is a combination of the interaction between purity (CCE) and fineness. Since both purity and fineness vary from one producer to another, there have been numerous attempts to devise numerical systems for evaluating quality, comparing sources, and serving as a basis for making adjustments in recommendations. Most systems are cumbersome in nature and somewhat difficult to understand, resulting in limited acceptance.

Recommended rates on Purdue soil test reports are based on 25 percent of the particles passing a 60 mesh sieve. information is provided on the back of the report, and in Table 5, for adjusting recommended rates according to differences in fineness. If more precision is desired in making adjustments, a procedure could be used by making slight modifications to a system recently developed at the University of Kentucky. It combines two fineness values and the purity (CCE) factor into one term called Relative Neutralizing Value (RNV). On the assumption that particles larger than 8 mesh are not effective in changing the soil pH during the first three years after application (see information In Table 4), the following formula is used to calculate the RNV:

$$RNV = \frac{(\text{\% passing 8 mesh} + \text{\% passing 60 mesh})}{2} \times \frac{CCE}{100}$$

Table 5. Limestone rate adjustment for fineness.

Rate recommended on soil test reports	Percent limestone passing a 60 mesh sieve			
	15-25	25-35	35-60	60+
2	2.5	2.0	1.5	1.5
4	5.5	4.0	3.0	3.0
6	8.0	6.0	5.0	4.5
8	10.0	8.0	6.5	5.5

This formula gives pure calcitic limestone ground so that all particles pass a 60 mesh sieve an RNV of 1 00:

$$RNV = \frac{(100+100)}{} \times \frac{100}{} = 100$$

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                2         100
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A standard RNV to use in making rate adjustments can be calculated according to the criteria formerly used for approving ACP cost-sharing funds for aglime: 1) 80% passing 8 mesh, 2) 25% passing 60 mesh, and 3) 80% CCE. The RNV of such a limestone is:

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          (80+25)     80
RNV =    -------  x ---  = 41
            2        100
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Rate adjustment uses the following formula:

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Adjusted rate:
                          41
      recommended rate X ---- of Aglime be applied
                          RNV
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An example is a recommended rate of 5 Ton/A and applying an aglime with an RNV of 59 (Indiana state average):

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                            41
        Adjusted rate: 5 X ---- - 3.5 tons/a.
                            59
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Many Indiana aglime producers participate in an annual voluntary testing program conducted cooperatively through the Indiana Mineral Aggregates Association and the Purdue Agronomy Department. Tests are made for CCE, fineness, percent calcium and percent magnesium. Results are available at limestone producers, fertilizer dealers, county extension offices, and county ASCS offices.

Tillage Practices and Nitrogen Placement and Soil Sampling. The quantity of limestone needed to correct an acid soil condition is influenced by the volume (depth) of soil with which the limestone will be mixed during tillage operations. Mixing ranges from none with continuous no-till to 12-14 inches with moldboard plows. Rates recommended on Purdue soil test reports are based on a tillage depth of 9 inches with a suggested 10 percent adjustment for each one inch variance in tillage depth and a maximum adjustment of 30 percent. Where a moldboard plow is used once every four years in a row cropping system, soil samples should be taken to plow-depth regardless of tillage practices in the intervening years.

Chisels do not mix the soil uniformly throughout the depth of operation; very little mixing occurs in the lower half of the chiseling depth.