A Guide to Selecting Agricultural Limestone Products

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ABSTRACT

Application of agricultural limestone or dolomite is an important means of maintaining soil acidity at levels that are best for maximum economical crop production. Illinois farmers apply more agricultural limestone per acre than any other farmers in the United States.

To select the best agricultural limestone product, farmers must consider such geologic, agronomic, and economic factors as the chemical composition of the stone, the particle size of the crushed limestone product, and the cost per ton of purchasing and transporting the agricultural limestone. The calculated effective neutralizing value (ENV) of a limestone involves the effects of both particle size and chemical composition on the acid-neutralizing capacity of the stone. ENV calculations provide an easy means of comparing one agricultural limestone product with another. To objectively select the best agricultural limestone to use in a particular case, careful cost comparisons that consider all factors must be made.

INTRODUCTION

Crushed limestone and dolomite for agricultural applications are major industrial mineral commodities in Illinois. Illinois farmers apply more agricultural limestone per acre than any other farmers in the United States. In 1976, of the 61.8 million tons of crushed stone produced in Illinois, more than 10 percent, 6.4 million tons, was agricultural limestone or dolomite. In 1977, the state of Illinois ranked second in the United States in total production of crushed stone and produced 7 percent of the total United States output (U.S. Bureau of Mines, 1978). Limestone and dolomite are quarried in about 60 of the 102 counties in Illinois. For many of the smaller operators, agricultural limestone or dolomite constitutes a major proportion of total annual production.

The purpose of this note is to provide farmers with some basic facts about limestone and dolomite and agricultural limestone products in order to make it easier for them to select the best product to suit their particular needs. The question of which quarry product is the best in a particular area often has no easy answer. As will be shown, geologic, agronomic, and economic factors all affect any judgement of the best product for use on a particular farm.

It is not the intent of this publication to supply the detailed information necessary to prepare a management program for agricultural liming. The local Agricultural Extension Service advisor can provide much more complete information on the effects of liming on yields, the influence of soil type on limestone requirements, and the overall economics of regular lime applications. The University of Illinois Cooperative Extension Service at Urbana-Champaign has several publications available on the use and correct application of agricultural limestone products. The *Agronomy Handbook* (University of Illinois Cooperative Extension Service, 1977-78, pages 29-57) has an extensive treatment of soil testing and fertility, and *Agronomy Facts, SF-79* (Tucker and Peck, 1972), discusses the importance and effects of application of agricultural limestone and dolomite. Portions of these publications have been quoted in this note.

CARBONATE ROCKS

Agricultural limestone and dolomite are quarried and crushed from rocks called *carbonate rocks* because of their chemical composition. In Illinois, carbonate rocks are sedimentary rocks originally deposited on the bottoms of shallow seas that repeatedly covered the area. The major constituents of these rocks are the whole and fragmented shells of animals and plants that lived in these oceans several hundreds of millions of years ago. Like the shells found along the ocean beaches of today, the shells of these ancient organisms were made mostly of the mineral calcite, having the chemical composition calcium carbonate $(CaCO_3)$. Sedimentary rocks made mostly of the mineral calcite are called *limestone*. Most carbonate rocks found in the central and southern thirds of Illinois are limestone.

Under some circumstances, chemical reactions in a limestone can alter its chemical and mineral composition. From a rock that is originally wholly calcite $(CaCO_3)$, the chemical reaction can make a rock that consists entirely of the mineral dolomite, having the chemical composition calcium magnesium carbonate $(CaMg(CO_3)_2)$. Most carbonate rocks in the northern third of Illinois are made of dolomite. Such rocks made mostly of the mineral dolomite

are called *dolomite* or *dolostone*. Throughout this note, the term *dolomite* will be used to refer to the rock; if the mineral dolomite is the substance being discussed, the distinction will be made clear in the sentence.

Mineral grains with chemical compositions intermediate between those of pure calcite and pure dolomite are almost unknown in ancient carbonate rocks. But carbonate rocks do occur that are mixtures of grains of calcite and dolomite. On a larger scale, carbonate rocks mined in a quarry may consist of interlayered beds of limestone and dolomite rocks, or patches of dolomite surrounded by limestone, or vice versa. Quarry operators rarely bother to separate such layers or patches of different kinds of rock; instead, they market a mixed product. For convenience, geologists use the following terms for such mixed carbonate rocks:

limestone:	0 to 10 % dolomite
dolomitic limestone:	10 to 50 % dolomite
calcareous dolomite:	50 to 90 % dolomite
dolomite:	90 to 100 % dolomite

IMPURITIES

The carbonate minerals in a limestone or dolomite do the work of neutralizing soil acidity. Impurities decrease the acid-neutralizing capacity of a rock by diluting the amount of carbonate mineral per unit volume of rock. Because limestone and dolomite form as accumulations of sediment on the bottom of the ocean, sediment grains other than carbonate minerals are the most common impurities. As is the case with the oceans of today, the principal contaminants found in ancient carbonate rocks are quartz sand and silt and clay minerals eroded from the land and transported to the sea by rivers.

Because carbonate rocks are made largely of the whole and fragmented shells of marine animals and plants, it is not unexpected that some limestones and dolomites contain small amounts of organic matter. Although rarely present in amounts greater than about 5 percent, organic matter can change the color of a limestone or dolomite.

Color and impurities

The color of a carbonate rock can give only a vague indication of its purity. A perfectly pure limestone or dolomite should be a brilliant, paper-white color, but even small amounts of some impurities can drastically alter the color. The degree of color change depends on both the amount and the nature of the impurities in the rock. Among the impurities that can affect the color of a carbonate rock to varying degrees are organic matter, silt and clay minerals, finely divided iron sulfide minerals, and iron oxide or hydroxide minerals.

Even small amounts of organic matter can drastically darken the color of a carbonate rock. Contamination with clay minerals may also result in some darkening of the color of the rock, but much more clay contamination is required to achieve the same amount of darkening as a very small amount of organic matter. Thus, two carbonate rocks of almost the same color may have widely differing carbonate contents because the color of the one is caused by organic matter and of the other by clay mineral contamination.

Iron sulfide minerals such as pyrite can occur in some limestones and dolomites. Pyrite is commonly associated with organic matter. When the grains of pyrite in a limestone or dolomite are extremely small and scattered throughout the rock, they can impart a pronounced dark gray or black color to the rock. Small amounts of both pyrite and organic matter can turn a limestone or dolomite almost black.

Carbonate rocks are often somewhat porous and permeable, allowing ground water to pass through them. Ground water can transport small amounts of iron oxide into the rock or can cause oxidation of iron-bearing minerals already in the rock. Such iron oxide or hydroxide minerals can result in a uniform or blotchy, orange or yellow stain.

It should be noted that, of all the possible coloring contaminants in carbonate rocks, only clay minerals and silt result in substantial contamination of the carbonate content of the rock. The fact that one quarry produces a whiter-looking agricultural limestone product than another is no indication that the whiter product is more effective in neutralizing soil acidity.

As will be shown, there are many factors that affect the acid-neutralizing capacity and efficiency of agricultural limestone products. The only way to be certain of choosing the most effective product is by examining and working with the chemical analysis and other characteristics of the products using the methods outlined in this note.

EVALUATING LIMESTONES

Calcium carbonate equivalent

Because limestone and dolomite are applied to agricultural acreage to neutralize excess soil acidity, it is important to be able to compare the theoretical acid-neutralizing capacities of various products. A useful figure for making this comparison is the *calcium carbonate equivalent* or CCE. This number expresses the acid-neutralizing capacity of a carbonate rock relative to the capacity of pure calcium carbonate (calcite). An absolutely pure limestone (all calcite) has a CCE of 100 percent. When measured relative to calcite, dolomite has a greater acid-neutralizing capacity per unit of weight because of the difference between the atomic weights of calcium (40) and magnesium (24). Pure dolomite has a CCE of 108.5 percent, but the greater value is essentially the result of the method of calculation. Dolomite should not automatically be considered more effective than limestone for agricultural purposes solely because of its higher CCE value. As will be shown, there are other factors to consider.

Calculating CCE values

If the analysis of a carbonate rock does not list a CCE value for the stone, the value can be calculated from the following:

$$CCE = (wt\% \ CaCO_3) + (1.187 \ x \ wt\% \ MgCO_3).$$

If the analysis does not list values for $CaCO_3$ and $MgCO_3$, but instead lists values for CaO, MgO, and CO_2, the CCE can be calculated from the following:

$$CCE = (1.785 \ x \ wt\% \ CaO) + (2.483 \ x \ wt\% \ MgO).$$

Some care should be exercised in evaluating and comparing CCE values of various products. Although a pure dolomite has a CCE value higher than a pure calcite, dolomite is more slowly soluble in acid than calcite. Thus, an impure dolomite may take considerably longer to neutralize the same amount of acid as an impure, nondolomitic limestone having the same CCE value. For comparison, the relative amounts of dolomite and limestone required for similar results in a 2- to 4-year period are shown in figure 1. The figure shows that dolomite, unless finely ground, may be much less efficient than limestone in rapidly neutralizing soil acidity (Tucker and Peck, 1972, p. 9).

Although there are no specific legal standards for minimum CCE values of agricultural limestone and dolomite, impurities that decrease the CCE value below about 80 percent are undesirable for either construction or agricultural purposes. Such rocks are quarried and sold only where no other satisfactory sources exist in the area.
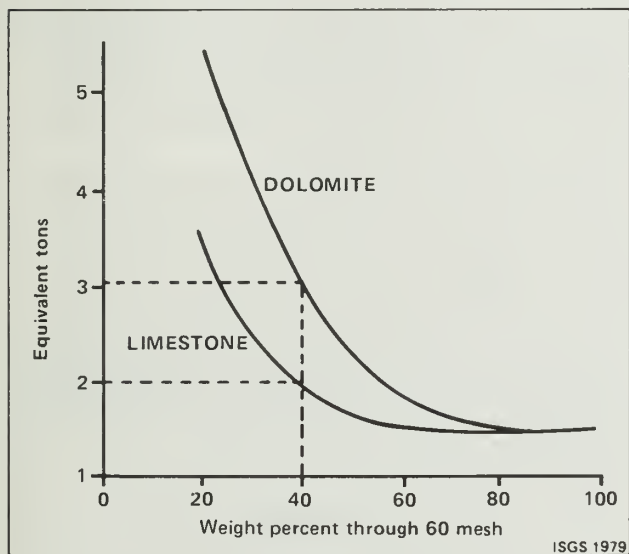
Figure 1. Tons per acre of limestone and dolomite of equivalent particle size required to give equivalent neutralizing of soil acidity over a 2-to 4-year period.

Particle size

The particle size of an agricultural limestone or dolomite product strongly affects the rate at which the product dissolves to neutralize soil acidity. The coarsest particles, those retained on an 8-mesh U.S. Standard sieve, have little immediate effect on soil acidity because they may take several years to dissolve. Particles in the range of 10 mesh to 28 mesh are only 14 percent as effective as particles finer than 100 mesh in neutralizing soil acidity in a given period of time (Tucker and Peck, 1972, p. 9).

Table 1 compiles the results of some studies of rates of solution for various size fractions of an agricultural limestone. Even after 8 years, only 25 percent of the particles more than 8 mesh in size have dissolved. Because the coarsest particles contribute little to the acid-neutralizing capacity of the product, additional limestone must be applied to compensate.

TABLE 1. Weight percent of limestone dissolved in several size fractions in 1, 4, and 8 years after application to soil (from Aldrich, 1961).

	Years after application		
Size fraction	1	4	8
Passing 60 mesh	100	100	100
30 to 60 mesh	50	100	100
8 to 30 mesh	20	45	75
Retained on 8 mesh	5	15	25

Table 2 shows the average particle-size distributions of agricultural limestone products at five east-central Illinois quarries. Only one of the quarries crushes a product in which more than 80 percent of the particles pass a number 8 sieve. As will be shown, the effects of particle size on rates of dissolution can be compensated for when determining the amount of a particular product to use for a particular application.

TABLE 2. Particle-size analyses of agricultural limestone products from selected quarries in east-central Illinois.[a]

Quarry number	Weight percent passing		
	8 mesh	30 mesh	60 mesh
1	57.94 ± 11.96	19.25 ± 5.01	12.56 ± 2.69
2	76.50 ± 8.00	31.38 ± 4.79	18.70 ± 3.31
3	65.61 ± 9.50	28.83 ± 6.13	18.90 ± 4.43
4	80.85 ± 2.72	34.60 ± 3.50	20.49 ± 2.99
5	78.85 ± 1.56	36.22 ± 4.46	22.01 ± 3.99

[a] Values are averages of 8- to 10-sieve analyses of samples collected monthly from stockpiles.

Fineness efficiency

The amounts of each size fraction dissolved in 1 year, as shown in table 1, can be used as *efficiency factors* to determine the relative efficiencies of various agricultural limestone products (University of Illinois Cooperative Extension Service, 1977-78, p. 31). Table 3 shows the particle-size analyses of the five east-central Illinois quarries from table 2 recalculated for the same particle-size intervals as those given in table 1. The weight percent of the stone in each particle-size interval, when multiplied by the corresponding 1-year efficiency factor selected from table 1, gives a number called a *fineness efficiency factor*. The sum of the fineness efficiency factors calculated for a particular agricultural limestone product gives the *total fineness efficiency* of the product. As an illustration of this calculation, the total fineness efficiency of the product from Quarry 3 has been determined in table 4.

TABLE 3. Particle-size analyses of agricultural limestone products from five selected quarries in east-central Illinois.[a]

| Size fraction | Quarry number | | | | |
	1	2	3	4	5
Passing 60 mesh	12.56	18.70	18.90	20.49	22.01
30 to 60 mesh	6.69	12.68	9.93	14.11	14.20
8 to 30 mesh	38.69	45.12	36.78	46.25	42.63
Retained on 8 mesh	42.06	23.50	34.39	19.15	21.15

[a] Caculated from average values in table 2.

TABLE 4. Calculation of fineness efficiency of limestone from Quarry 3 of table 3.[a]

Size fraction	Weight % / 100	Efficiency factor	Fineness efficiency
Passing 60 mesh	0.189	100	18.90
30 to 60 mesh	0.099	50	4.95
8 to 30 mesh	0.3678	20	7.36
Retained on 8 mesh	0.3439	5	1.72
		Total fineness efficiency	32.93

[a] Efficiency factor is from 1-year values of table 1.

Effective neutralizing value

The effective neutralizing value is perhaps the ultimate tool for making comparisons among various agricultural limestone products. This calculated percentage combines the fineness efficiency of the stone and the calcium carbonate equivalent. The number can be used to calculate how much more or less of one agricultural limestone pro-

duct must be applied to give the same acid neutralizing effect as another (University of Illinois Cooperative Extension Service, 1977-78, p. 31-32). The *effective neutralizing value* (ENV) of an agricultural limestone product is determined by multiplying the CCE value of the stone by the total fineness efficiency. Samples from Quarry 3, for example, have an average CCE of 92 percent. So, the ENV of the stone from Quarry 3 is *32.93 x 0.92 = 30.30 percent.*

Comparing application rates

Figure 2 shows the charts used by the University of Illinois Cooperative Extension Service to determine the application rates for agricultural limestone. The charts take into account the general soil type, the soil acidity or pH, and the cropping system. A 9-inch plowing depth is assumed. Applications rates from these charts apply to a stone having a total fineness efficiency of 51.5 and a CCE of 90 percent. Thus, the ENV of the typical limestone assumed for the charts is 46.35 percent.

To calculate the application rate for a stone having a different ENV, due predominantly to a difference of fineness efficiency, divide the ENV of that stone into the ENV of the typical stone of the chart, and multiply the result by the tonnage rate originally determined from the chart. For example, for grain farming in soil type C and an initial soil pH of 5.5, Chart 1 of figure 2 indicates an application rate of 3 tons per acre of typical limestone to bring the soil pH to about 6. If stone from Quarry 3 of table 4 is to be used, then the calculated tonnage multiplier would be:

$$\frac{ENV\ of\ Chart\ 1}{ENV\ of\ Quarry\ 3} \qquad \frac{46.35\ \%}{30.30\ \%} = 1.53$$

Multiplying this tonnage multiplier by the tonnage rate of 3 tons per acre originally determined from Chart 1 gives an application rate of 4.59 tons per acre for stone from Quarry 3 to produce the same acid-neutralizing effect as the typical stone of the charts.

Because limestone or dolomite ground to a fineness comparable to that of the typical stone of the charts in figure 2 is expensive to produce, a premium price will therefore be asked for such a product. As will be shown, however, the cost of higher application rates for a coarser stone can be less than the cost of importing a smaller amount of higher-priced, finer-ground stone from some distance away. Careful cost comparisons should govern the choice of stone to use for agricultural liming.

ECONOMIC CONSIDERATIONS

When stone for liming is purchased from a nearby quarry (no more than about 35 miles distant) the cost of the stone is the dominant expense. Commercial
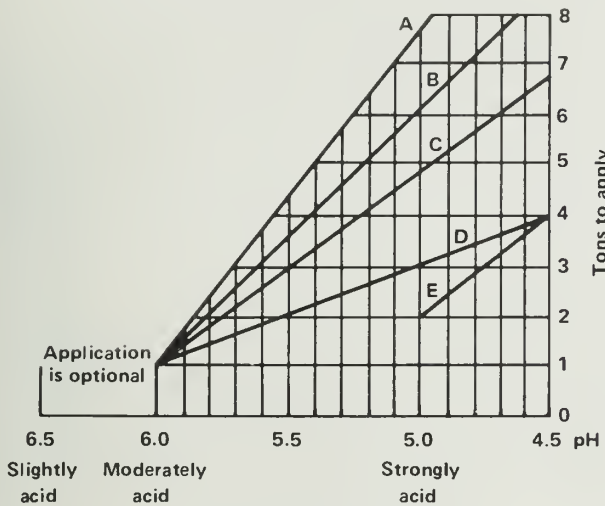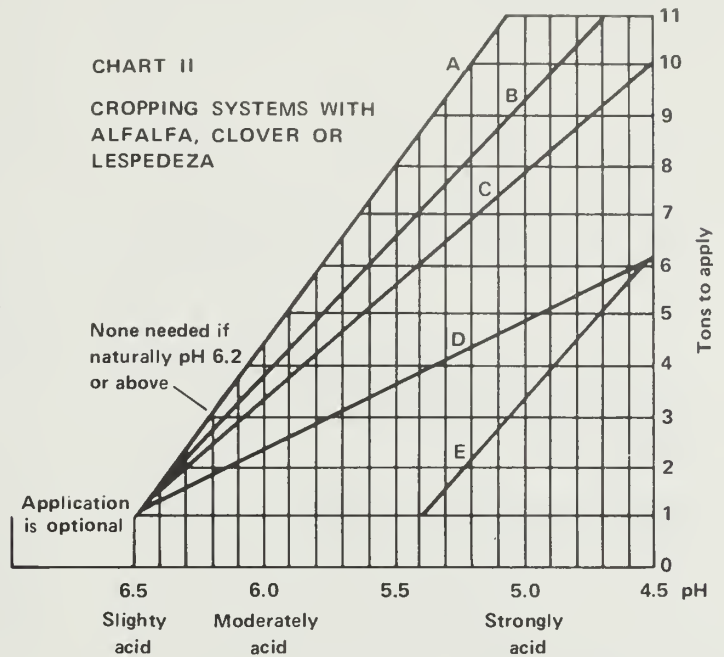
Figure 2. Charts for determining tonnage of limestone or dolomite necessary to maintain soil acidity at recommended levels for maximum production for the two main cropping systems of Illinois.

trucking rates for hauling less than 5,000 tons of stone are about equal to, or less than, the cost of the stone for hauls of up to 35 miles. For longer hauls, the trucking rates for each ton of stone are higher than the cost per ton of the stone at the quarry (FOB price). Hauls across state lines may be even more costly than those within a state because of the differing rate structures in interstate commerce. To demonstrate the influence of transportation costs and to illustrate the use of effective neutralizing values (ENV) in comparing the costs of agricultural limestone products, four cases will be outlined below.

Let us say that a farmer has learned from soil testing that he should apply limestone having an ENV of 46.35 percent at an average rate of 5 tons per acre to his 500 acres of corn and soybean ground. A local quarry about 35 miles from the farm sells a stone that has an ENV of 30 percent, primarily because of its coarseness. A more distant quarry, about 80 miles from the farm, sells a stone having a CCE almost equal to the local quarry, but the ENV of this stone is 40 percent because of its higher total fineness efficiency value. Because of the increased cost of fine grinding, the distant quarry charges a premium price

for its agricultural limestone. The farmer evaluated the two cases in the following way:

Case 1
Local Quarry, 30% ENV

ENV correction is $\frac{46.35}{30.00} = 1.545$. *So, 1.545 x 5 tons/acre*

gives an application rate of 7.73 tons/acre.

Price of limestone is $3.75 per ton for sales of 1,000 tons or more.

7.73 tons/acre x 500 acres = 3,865 tons @ $3.75 per ton = $14,493.75.

Commerical trucking rates are $3.02 per ton for a 35-mile one-way loaded haul to a single dump point.

$3.02 per ton x 3,865 tons = $11,672.30. Total delivered cost of stone = $26,166.05.

Case 2
Distant Quarry, 40% ENV

ENV correction is $\frac{46.35}{40.00} = 1.16$. *So, 1.16 x 5 tons/acre*

gives an application rate of 5.8 tons/acre.

Price of limestone is $4.25 per ton.

5.8 tons/acre x 500 acres = 2,900 tons @ $4.25 per ton = $12,325.00

Commercial trucking rates are $5.78 per ton for an 80 mile one-way loaded haul to a single dump point.

$5.78 per ton x 2,900 tons = $16,762.00. Total delivered cost of stone = $29,087.00.

Although the price of the stone at the distant quarry is higher than that at the local quarry, the lower tonnage requirements of the higher ENV stone result in a lower cost for the stone at the distant quarry. However, the much greater cost of transporting the stone from the distant quarry increases the total delivered cost of the stone by almost $3,000 over that from the local quarry. Stone from the distant quarry would have to have an ENV of more than 44.50 percent to bring the total delivered cost down to that of the local quarry.

The farmer also calculated the cost of transporting the stone in his own 20-ton spreader truck. He estimates that it costs him about 3 cents per ton-mile to operate the truck. To transport the 3,865 tons of stone from the local quarry would require 193.25 loads, each requiring a round trip of 70 miles at a cost of $0.60 per mile (*20 tons x 3 cents per ton-mile*). The total haulage cost would thus be $8,116.50 (*193.25 loads x 70 miles x $0.60 per mile*). This, added to the price of the stone at the quarry, gives a total delivered cost of $22,610.25 for the stone.

For stone from the distant quarry, the 2,900 tons of stone would require 145 round trips of 160 miles at $0.60

per mile, or a cost of $13,920.00. Total delivered cost of the stone from the distant quarry would then be $26,245.00. This exceeds the cost of the stone from the local quarry by almost $4,000. Only if the stone from the distant quarry had an ENV of 46.35 percent, that of a "typical limestone" from the charts in figure 2, would its total delivered cost equal that of the local quarry stone.

Although these cases provide only a partial cost analysis, they do illustrate the strong influence of transportation charges on the total delivered cost of agricultural limestone. Costs of transportation can outweigh the total cost of the stone at the quarry. Given two quarries an equal distance from a farm, the limestone having the higher ENV will certainly be less expensive to transport because of the lower application rate and, therefore, lower total tonnage of stone required. However, a higher price charged for stone of higher ENV may make it more expensive, overall, than stone of lower ENV and lower price. Careful cost analysis, including transportation costs, is the best way to ensure choosing the most economical product for use in liming agricultural fields.

BENEFITS OF LIMING

Application of agricultural limestone or dolomite is an important means of maintaining soil acidity at levels that are best for maximum economical crop production. The University of Illinois Cooperative Extension Service lists the following benefits from maintaining soil acidity at recommended levels by regular liming of fields:

1. Manganese and aluminum, which may be available in amounts great enough to be toxic in acid soils, are much less soluble and less available in soils with near-neutral acidity.
2. The micro-organisms that speed the decay of plant materials, thereby releasing nitrogen and phosphorus into the soil, grow more rapidly and operate more effectively in neutral to slightly acid soils.
3. Growth of nodule-forming, nitrogen-fixing bacteria on alfalfa, clover, and soybeans is favored in neutral to only slightly acid soils.
4. The minor elements essential for plant growth have the best balance of availability in neutral to slightly acid soils.
5. Phosphorus is more available in neutral to slightly acid soils than in strongly acid soils.

Under prolonged production, Illinois soils tend to become strongly acid unless limestone or dolomite is applied at regular intervals. Annual application of large amounts of nitrogen (more than 150 pounds per acre) can cause severe increases of soil acidity. Acidification of soil by nitrogen application is caused by both direct and indirect effects. Plants take up nitrogen from the soil in the

form of soluble nitrate ions. When nitrogen is applied to the soil in the form of anhydrous ammonia (NH_3), ammonium nitrate (NH_4NO_3), ammonium sulfate ((NH_4)$_2SO_4$), or urea (H_2NCONH_2), the released ammonia is converted to nitrate ions (NO_3) in the soil. This releases hydrogen ions (H^+) that increase the soil acidity. Indirectly, the increased plant growth caused by the nitrogen application takes up greater amounts of the base ions calcium (Ca^{++}), magnesium (Mg^{++}) and potassium (K^+), thus relatively enriching the soil in hydrogen ions. Greater plant growth also increases the production of carbonic acid (H_2CO_3) from plant respiration. Figure 3 shows the effects of the addition of various amounts of nitrogen in various forms to the Pullman clay loam soil.

Five years of annual nitrogen application caused the pH change shown for a Pullman clay loam soil.

AS = ammonium sulfate
AN = ammonium nitrate
U = urea
AA = anhydrous ammonium

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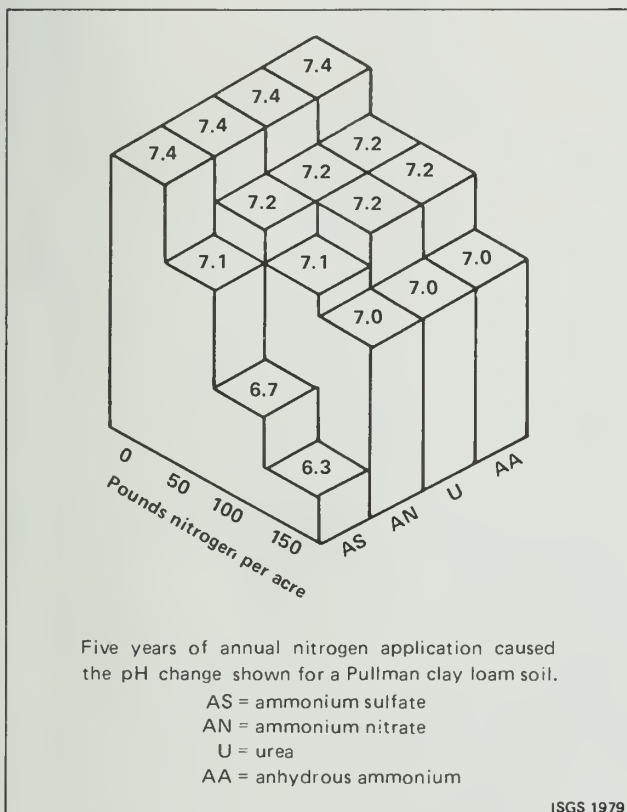
Figure 3. Effect of nitrogen application on soil pH.

On the pH scale, a value of 7 is neutral. Values greater than 7 are considered basic and values less than 7 are acidic. In figure 3, although almost all the pH values are greater than 7, the application of nitrogen causes the pH of soil to decrease from more basic to less basic values, indicating increasing acidity of the soil. The most drastic effects are found when applying ammonium sulfate fertilizers. Regular applications of agricultural limestone or dolomite can prevent this increase of acidity. A common rule of thumb used by the Cooperative Extension Service is that 3 to 4 pounds of agricultural limestone should be aplied for each

pound of nitrogen supplied to the soil by anhydrous ammonia, ammonium nitrate, and urea fertilizers. For ammonium sulfate applications, the amounts of limestone required are even higher.

CONCLUSIONS

1. Outward appearance, especially color, of agricultural limestone or dolomite is a poor indicator of the quality and effectiveness of a product for liming agricultural fields.
2. The particle-size distribution of an agricultural limestone or dolomite product has a strong influence on the effectiveness of the product for neutralizing excess soil acidity. Coarser particles may take years to dissolve and therefore contribute little to the neutralizing process.
3. When the particle-size distribution of an agricultural limestone product is known, efficiency factors can be used to calculate a *total fineness efficiency* value that is useful for examining the influence of particle-size distributions of various products.
4. The *calcium carbonate equivalent* (CCE) can be easily calculated from chemical analyses of carbonate rocks and provides a satisfactory means of comparing agricultural limestone products when grain-size distributions are unknown.
5. The *effective neutralizing value* (ENV) of an agricultural limestone combines total fineness efficiency value and the calcium carbonate equivalent to provide a highly useful tool for comparing various agricultural limestone products.
6. Careful economic analysis, taking into account the differing ENV of the limestone and the varying costs of transportation, should be the major method used to select the best product for agricultural liming.

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