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University of Kentucky
College of Agriculture, Food and Environment
Cooperative Extension Service

Agricultural Lime Recommendations Based on Lime Quality

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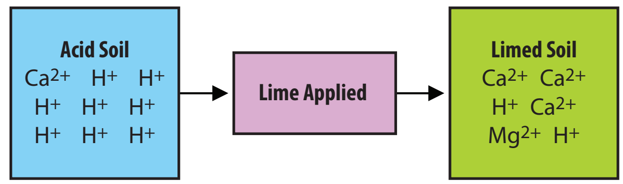
Soil acidity is one of the most important soil factors affecting crop growth and ultimately, yield and profitability. It is determined by measuring the soil pH, which is a measure of the amount of hydrogen ions in the soil solution. As soil acidity increases, the soil pH decreases. Soils tend to be naturally acidic in areas where rainfall is sufficient to cause substantial leaching of basic ions (such as calcium and magnesium), which are replaced by hydrogen ions. Most soils in Kentucky are naturally acidic because of our abundant rainfall. Nitrogen fertilization can also contribute to soil acidity as the nitrification of ammonium increases the hydrogen ion concentration in the soil through the following reaction:

$$NH_4^+ + 2O_2^- \text{-->} NO_3^- = H_2O + 2H^+$$

Periodically, agricultural limestone (ag lime) is needed to neutralize soil acidity and maintain crop productivity. Ag lime replaces exchangeable acidic ions, such as hydrogen ions, with calcium (Ca^{2+}) and some magnesium (Mg^{2+}) ions, which are considered basic (Figure 1).

The chemical reactions that take place in soil when lime is applied are shown in Figure 2. The lime dissolves to form calcium, bicarbonate, and hydroxide ions. The hydroxide neutralizes soil acidity by combining with hydrogen ions to form water. As the concentration of hydrogen ions decreases, the pH increases.

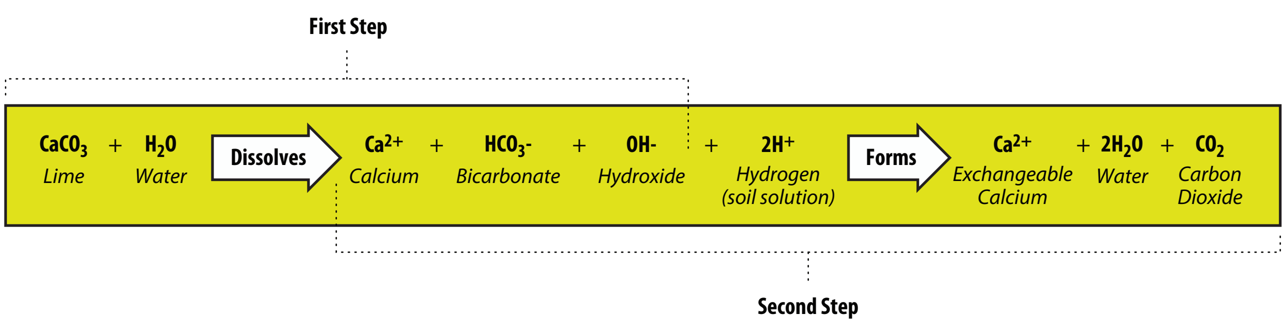
Figure 1. Liming acid soils increases exchangeable Ca and Mg.



The majority of the hydrogen ions are actually held on cation exchange sites. To effectively neutralize soil acidity, hydrogen ions must be removed from both the soil solution and the exchange sites. While soil pH only measures the solution hydrogen, the buffer pH is an indication of exchangeable acidity and how much ag lime is actually needed. It is possible for two soils to have the same water pH but different lime requirements due to the different amounts of exchangeable acidity.

There are two type of agricultural limestone, calcitic and dolomitic. Calcitic limestone contains calcium carbonate, where dolomitic limestone contains calcium and magnesium carbonate. Both Ca and Mg are essential plant nutrients. Limestone also increases the availability of phosphorus (P) and molybdenum (Mo).

Figure 2. The chemical reaction that occurs when ag lime is added to an acid soil.



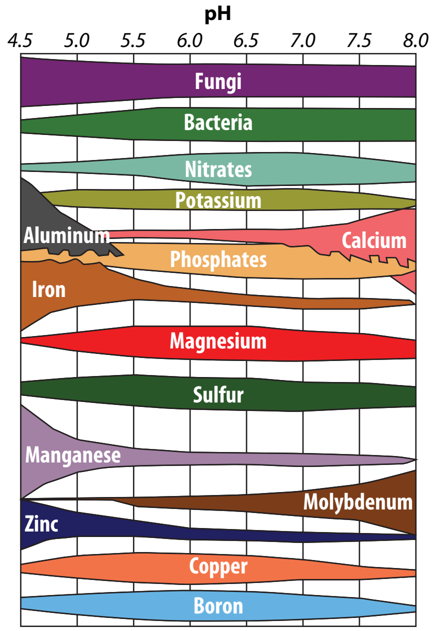


Figure 3. The availability of plant nutrients and toxic elements is controlled by soil pH.

Lime decreases the plant availability of aluminum and manganese, thus lowering the risk of their toxicity, a common problem in very acid soils. Lime also may decrease the availability of zinc and iron (Figure 3). Finally, agricultural lime decreases the solubility of potentially harmful heavy metals in soil by immobilizing them so that less of the metals is absorbed into water, plants, and ultimately the food chain.

Lime Quality: Chemical and Physical Properties

Agricultural lime quality can vary tremendously depending on the chemical properties and particle size caused by physical grinding of the stone.

Chemical Properties

Chemical properties determine the amount of acid that can be neutralized and are a function of the minerals in the stone. So that different sources of lime can be easily compared, the amount of acid neutralized by a lime of unknown purity is compared to the amount neutralized by pure calcium carbonate. If the unknown sample neutralizes only half as much acidity, then we say that it is equivalent to 50% calcium carbonate (or 50% $CaCO_3$). Occasionally, when the limestone source has large amounts of magnesium, the percent $CaCO_3$ can be greater than 100, because per unit of weight, magnesium carbonate neutralizes more acidity than calcium carbonate.

Physical Properties

Figure 4. An ag lime sample divided into the three sizes: coarser than 10-mesh (top), 10 to 50-mesh (lower left), and finer than 50-mesh (lower right).

The important physical characteristic is the size of the particles in ground limestone. Figure 4 shows the different sizes of limestone. Agricultural limestone reacts more quickly when the particles are very small because the limestone has a better chance to dissolve and to neutralize soil acidity. In Kentucky, the size of limestone particles is described by the amount of material that can pass through a 10-mesh sieve, which contains 2-mm square holes (approximately 1/32 inch), and a 50-mesh sieve, which contains 0.3-mm square holes (1/200 inch). The particles passing through a 50-mesh sieve are considered small enough to completely dissolve in soil and be 100% effective.

Particles passing through the 10-mesh sieve but not passing through the 50-mesh sieve are too big to be completely effective but are considered to be 50% effective during a three-year period. Particles not passing through the 10-mesh sieve are too large to dissolve in a three to four-year period, so these particles are considered to be 0% effective.

The chemical characteristic, assessed as percent calcium carbonate equivalence, and the physical characteristic, assessed as the size of the particles, are combined into one value that quantifies the effectiveness of the limestone. This value is known as the *relative neutralizing value,* which is abbreviated RNV.

The RNV is calculated as:

RNV (%) =
CCE/100 * [(% between 10 and 50 mesh + % less than 50 mesh)/2]

Variability of Ag Lime Quality in Kentucky

Even when ag lime is applied according to soil test recommendations, the actual adjustment in soil pH is not always predictable, because the quality of Kentucky ag lime varies widely among quarries and over time. This variability is due to changes in the purity of the limestone strata being mined and normal wear of the crusher, which causes the fineness of limestone particles to vary.

Table 1 shows the range of purity (% $CaCO_3$), fineness, and RNV values for three selected quarries located in Kentucky for a seven-year period. In general, ag lime purity and fineness varied greatly among these quarries, and quality varied within each quarry over the seven-year period. The RNVs ranged from a low of 24% to a high of 99%. The purity of the limestone is similar between Quarry #1 and Quarry #3, but the RNV is generally higher for quarry #3 due to a greater % of material passing a #50 sieve with quarry #3. Quarry #3 had one year where the % material passing a #50 sieve was 43%, which coincided with the RNV of 63% for quarry #3. Quarry #2 has the lowest RNV for the three quarries reported due to lower purity and larger limestone particle size compared to the other two quarries. In the past, the University of Kentucky Soil Testing Laboratory based ag lime recommendations on an RNV of 67%. The county Cooperative Extension agent, ag supplier, or farmer was responsible for correcting the lab recommendation for the RNV of the local ag lime.

New Lime Quality Program

The Kentucky agricultural limestone law was passed in an attempt to ensure that a lime of reasonable quality would be available to Kentucky farmers. This law (KRS 250.650 to 250.720) was passed by the 1960 General Assembly and became effective June 16, 1960. The Kentucky Department of Agriculture was charged with administering the law as it pertained to "agricultural limestone," meaning "limestone used for the purpose of neutralizing the acidity of soil and thereby improving its fertility."

KRS 250.670 considers ground limestone to be agricultural limestone only if it meets the following three minimum standards of quality:

1. 80% calcium carbonate equivalence ($CaCO_3$)
2. 90% of the product passes a 10-mesh wire-screen sieve
3. 35% passes a 50-mesh wire-screen sieve

In the past, product not meeting these standards has been reported as "failed to meet Kentucky standards for ag lime." However, banning the sale of product for not meeting the standards has not been enforced except through voluntary compliance by the crushed stone industry.

The three quality factors—calcium carbonate content, percent of material passing a 10-mesh sieve, and percent of material passing a 50-mesh sieve—not only have made enforcement of quality standards difficult, but also have made it hard to compare the relative effectiveness of different sources of ag lime.

Sometimes ag lime sources could fail to pass the criteria but actually have a higher agronomic value than other sources meeting the minimum requirements. For this reason, the ag lime quality program was changed in 2007. Under the new program, the Kentucky Department of Agriculture samples and tests the quality factors of ag lime sold in Kentucky and provides the data to the Cooperative Extension Service, crushed stone operators, and others.

Table 1. Range and (mean) in ag lime quality measured from selected quarries across Kentucky over a 7-year period (2007-2013).

Quarry	CaCO3 (%)	% of Material Passing #10 Sieve	% of Material Passing #50 Sieve	RNV (%)
Quarry #1	95-105 (98)	89-93 (90)	34-48 (40)	60-71 (64)
Quarry #2	72-89 (84)	55-72 (63)	10-23 (17)	24-39 (33)
Quarry #3	91-100 (94)	90-100 (99)	43-100 (89)	63-99 (88)

Extension and the operators then inform users through outreach education about the quality of ag lime available to them. Users are able to make informed decisions about the value of a specific lime source based on RNV, how much they need to apply, and the price per ton. As a result, the sale of ag lime is controlled in the marketplace by informed users. The purpose of this change was to ensure Kentucky farmers of a readily available source of reasonable quality ag lime at an affordable cost.

Sampling

All sources of ag lime are sampled in January for the spring liming season and in July for the fall season. Sampling equipment and procedures are in accordance with American Society for Testing and Materials (ASTM) standards. If piles are separated from one another or if sections of a large stockpile are clearly different, each is sampled separately.

Each sample consists of at least 10 sub-samples taken from different locations of the pile in order to provide a representative sample of each distinct pile. The 10 sub-samples are sent to the lab and combined for analysis.

Analyses

In the laboratory, the moisture content is determined for each sample by oven drying. A particle size is determined by using a nested configuration of both a 10- and a 50-mesh sieve. The results are reported as the percentage of the sample that passes through each of the sieves. In addition, the calcium carbonate content (% $CaCO_3$) is determined by dissolving a portion of the sample in hydrochloric acid and gently boiling the mixture for five minutes. Titration with sodium hydroxide is then used to determine the % $CaCO_3$. The RNV is calculated using the formula on page 2.

New Lime Recommendations

All recommendations for agricultural lime made by the Cooperative Extension Service at the University of Kentucky are made based on 100% effective lime (100% RNV). Limestone recommendations can also be determined from Table 2 with the soil water pH and the soil buffer pH. The soil buffer pH must be obtained using either the SMP or Sikora buffer methods. The recommendations are not valid for any other buffer method. Choose the table that has the target pH desired (6.4, 6.6, or 6.8). Then, using the soil pH and the buffer pH obtained from the soil test, select the 100% effective lime recommendation that will raise the soil pH to the target pH. This method increases the assurance that the amount of lime needed to neutralize the soil acidity will be applied.

RNV (Lime Quality) Reports

After the Kentucky Department of Agriculture samples and analyzes each ag lime source, the RNVs will be published and made available to the public at all county Extension offices and on the University of Kentucky Division of Regulatory Services Web site at http://soils.rs.uky.edu/technical_Info/

In addition, quarries, lime haulers, and other lime selling outlets should also maintain records of the RNV from their source(s) of lime. Soil test reports from UK Regulatory Services report the most recent RNV values for quarries closest to the county from which the soil sample was submitted.

Table 2. Rate of 100% effective limestone needed to raise soil pH to a desired level.

Target pH = 6.4: *corn, soybean, small grains, cool-season grass hay and pasture, bermudagrass, native warm-season grasses, sudangrass, millets, sorghum-sudangrass hybrids, lawns, tree fruits, strawberries, blackberries, raspberries, and grapes*

Water pH[1]	Buffer pH[1] 5.5	5.7	5.9	6.1	6.3	6.5	6.7	6.9	Not Known
	100% Effective Lime Rate (tons/acre)								
4.5	4.67	4.0	4.0	3.33	2.67	2.67	2.0	2.0	2.67
4.7	4.67	4.0	4.0	3.33	2.67	2.67	2.0	2.0	2.67
4.9	4.67	4.0	4.0	3.33	2.67	2.67	2.0	2.0	2.67
5.1	4.67	4.0	3.33	3.33	2.67	2.0	2.0	1.33	2.67
5.3	4.67	4.0	3.33	2.67	2.67	2.0	2.0	1.33	2.33
5.5	4.0	3.33	3.33	2.67	2.67	2.0	1.33	1.33	2.00
5.7	4.0	3.33	2.67	2.67	2.0	2.0	1.33	1.33	1.67
5.9	-	3.33	2.67	2.0	2.0	1.33	1.33	0.67	1.33
6.1	-	-	2.0	2.0	1.33	1.33	0.67	0.67	1.00

Target pH = 6.6: *tobacco*

Water pH[1]	Buffer pH[1] 5.5	5.7	5.9	6.1	6.3	6.5	6.7	6.9	Not Known
	100% Effective Lime Rate (tons/acre)								
4.5	4.67	4.0	4.0	3.33	2.67	2.67	2.0	2.0	2.67
4.7	4.67	4.0	4.0	3.33	2.67	2.67	2.0	2.0	2.67
4.9	4.67	4.0	4.0	3.33	2.67	2.67	2.0	2.0	2.67
5.1	4.67	4.0	3.33	3.33	2.67	2.0	2.0	1.33	2.67
5.3	4.67	4.0	3.33	2.67	2.67	2.0	2.0	1.33	2.33
5.5	4.0	3.33	3.33	2.67	2.67	2.0	1.33	1.33	2.00
5.7	4.0	3.33	2.67	2.67	2.0	2.0	1.33	1.33	1.67
5.9	-	3.33	2.67	2.0	2.0	1.33	1.33	0.67	1.33
6.1	-	-	2.0	2.0	1.33	1.33	0.67	0.67	1.00

Target pH = 6.8: *alfalfa, alfalfa/cool-season grass mixtures*

Water pH[1]	Buffer pH[1] 5.5	5.7	5.9	6.1	6.3	6.5	6.7	6.9	Not Known
	100% Effective Lime Rate (tons/acre)								
4.5	4.67	4.67	4.67	4.00	3.33	3.33	2.67	2.00	4.00
4.7	4.67	4.67	4.67	4.00	3.33	3.33	2.67	2.00	4.00
4.9	4.67	4.67	4.67	4.00	3.33	3.33	2.67	2.00	4.00
5.1	4.67	4.67	4.67	4.00	3.33	3.33	2.67	2.00	4.00
5.3	4.67	4.67	4.67	4.00	3.33	2.67	2.00	2.00	3.67
5.5	4.67	4.67	4.00	3.33	3.33	2.67	2.00	2.00	3.33
5.7	4.67	4.67	4.00	3.33	3.33	2.67	2.00	1.33	3.00
5.9	-	4.00	3.33	3.33	2.67	2.67	2.00	1.33	2.33
6.1	-	-	3.33	2.67	2.67	2.00	1.33	1.33	2.00
6.3	-	-	-	2.00	2.00	2.00	1.33	0.67	1.67
6.5	-	-	-	-	1.33	1.33	1.33	0.67	1.33

[1] From soil test.

Water pH of Sample

Bulk Lime Recommendation

Because agricultural limestone is rarely 100% effective, the amount of bulk lime needed will need to be determined for each lime source available, based on the RNV. The bulk lime recommendation can be determined from Table 3 using the 100% effective lime recommendation and the RNV for the lime to be purchased. It can also be determined using the formula

Bulk Lime = 100% Effective Lime Recommendation ÷ RNV x 100.

The bulk lime values in Table 3 are rounded to the nearest 0.5 ton. Therefore, the amount calculated by the formula above will not always be the same as the amount in Table 3.

In the past, lime recommendations were based on an RNV of 67%, which is approximately the average quality of limestone across Kentucky. Limestone quality varies greatly across the state, ranging from slightly over 100% to 50% or less. If the RNV of your lime source is unknown, use the old assumption of 67%. However, realize that using the correct RNV better assures the desired change in pH.

Table 3. Converting from 100% effective lime to bulk lime.

	100% Effective Lime Rate (tons/acre)												
	0.67	**1.00**	**1.33**	**1.67**	**2.00**	**2.33**	**2.67**	**3.00**	**3.33**	**3.67**	**4.00**	**4.33**	**4.67**
RNV %	**Bulk Lime Rate (tons/acre)**												
40	2.0	2.5	3.5	4.0	5.0	6.0	6.5	7.5	8.5	9.0	10.0	11.0	12.0
42	1.5	2.5	3.5	4.0	4.5	6.0	6.5	7.0	8.0	9.0	9.5	10.5	11.0
44	1.5	2.5	3.0	3.5	4.5	5.5	6.0	7.0	7.5	8.5	9.0	10.0	10.5
46	1.5	2.0	3.0	3.5	4.0	5.0	5.5	6.5	7.5	8.0	9.0	9.5	10.0
48	1.5	2.0	3.0	3.5	4.0	5.0	5.5	6.5	7.0	7.5	8.5	9.0	10.0
50	1.5	2.0	3.0	3.5	4.0	4.5	5.5	6.0	6.5	7.5	8.0	8.5	9.5
52	1.5	2.0	2.5	3.0	4.0	4.5	5.0	6.0	6.5	7.0	7.5	8.5	9.0
54	1.5	2.0	2.5	3.0	3.5	4.5	5.0	5.5	6.0	7.0	7.5	8.0	9.0
56	1.5	2.0	2.5	3.0	3.5	4.0	5.0	5.5	6.0	6.5	7.0	8.0	8.5
58	1.5	1.5	2.5	3.0	3.5	4.0	4.5	5.0	6.0	6.5	7.0	7.5	8.0
60	1.0	1.5	2.0	2.5	3.0	4.0	4.5	5.0	5.5	6.2	6.5	7.5	8.0
62	1.0	1.5	2.0	2.5	3.0	3.5	4.0	5.0	5.5	6.0	6.5	7.0	7.5
64	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	6.0	6.5	7.0	7.5
66	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0
Unknown*	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0
68	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0
70	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	5.5	6.0	6.5
72	1.0	1.5	2.0	2.5	3.0	3.5	3.5	4.0	4.5	5.0	5.5	6.0	6.5
74	1.0	1.5	2.0	2.5	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5
76	1.0	1.5	2.0	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	5.5	6.0
78	1.0	1.5	1.5	2.0	2.5	3.0	3.5	4.0	4.5	4.5	5.0	5.5	6.0
80	1.0	1.5	1.5	2.0	2.5	3.0	3.5	4.0	4.0	4.5	5.0	5.5	6.0
82	1.0	1.5	1.5	2.0	2.5	3.0	3.5	3.5	4.0	4.5	5.0	5.5	5.5
84	1.0	1.0	1.5	2.0	2.5	3.0	3.0	3.5	4.0	4.5	5.0	5.0	5.5
86	1.0	1.0	1.5	2.0	2.5	2.5	3.0	3.5	4.0	4.5	4.5	5.0	5.5
88	1.0	1.0	1.5	2.0	2.5	2.5	3.0	3.5	4.0	4.0	4.5	5.0	5.5
90	1.0	1.0	1.5	2.0	2.0	2.5	3.0	3.5	3.5	4.0	4.5	5.0	5.0
92	1.0	1.0	1.5	2.0	2.0	2.5	3.0	3.5	3.5	4.0	4.5	4.5	5.0
94	1.0	1.0	1.5	2.0	2.0	2.5	3.0	3.0	3.5	4.0	4.5	4.5	5.0
96	1.0	1.0	1.5	1.5	2.0	2.5	3.0	3.0	3.5	3.8	4.0	4.5	5.0
98	1.0	1.0	1.5	1.5	2.0	2.5	2.5	3.0	3.5	3.8	4.0	4.5	5.0
100	1.0	1.0	1.5	1.5	2.0	2.5	2.5	3.0	3.5	3.5	4.0	4.5	4.5

*Unknown RNV assumes 67%.

Bulk Lime Determination

Two examples of determining bulk lime application rates are presented below.

Example 1

Soil water pH........... 5.7
Soil buffer pH 6.7
Target pH.................. 6.4
RNV of ag lime 54%

Soil water pH, soil buffer pH, and target pH are used to provide a recommendation for 100% effective lime at 1.33 tons/acre (see Table 2). This value will be the lime recommendation shown on a University of Kentucky soil test report.

Using Table 3: Use 100% effective lime rate of 1.33 tons/acre to identify the correct column and the RNV of 54% to identify the correct row. The intersection of the column and row is the bulk lime application rate of 2.5 tons/acre.

Using the formula (from page 5): Bulk lime rate = 1.33 tons/acre ÷ 54 x 100 = 2.5 tons/acre. Calculated value is already on a half-ton basis. No rounding is necessary.

Example 2

Soil water pH........... 5.5
Soil buffer pH 6.5
Target pH.................. 6.4
RNV of ag lime 64%

Soil water pH, soil buffer pH, and target pH are used to provide a recommendation for 100% effective lime at 2 tons/acre (see Table 2). This value will be the lime recommendation shown on a University of Kentucky soil test report.

Using Table 3: Use 100% effective lime rate of 2 tons/acre to identify the correct column and the RNV of 64% to identify the correct row. The intersection of the column and row is the bulk lime application rate of 3 tons/acre.

Using the formula (from page 5): Bulk lime rate = 2 tons/acre ÷ 64 x 100 = 3.1 tons/acre. Round the calculated value of 3.1 to the nearest whole ton to achieve a value of 3 tons/acre.

Economics

Recommendations based on 100% effective lime allows comparison of lime values more easily from different sources in order to obtain the best buy. The cost of applying two sources of lime is shown below for a situation in which 2 tons/acre of 100% effective lime is recommended for a field of 50 acres.

Source 1

RNV of ag lime 54%
Cost............................ $15/ton spread

Bulk lime rate = 2 tons/acre ÷ 54 x 100 = 3.7 tons/acre

Round calculated value of 3.7 to nearest half-ton = 3.5 tons/acre.

Cost of lime = 3.5 tons/acre x $15/acre x 50 acres = $2,625.

Source 2

RNV of ag lime 67%
Cost............................ $15/ton spread

Bulk lime rate = 2 tons/acre ÷ 67 x 100 = 3 tons/acre

Calculated value is already on a whole-ton basis. No rounding is necessary.

Cost of lime = 3 tons/acre x $15/acre x 50 acres = $2,250.

Source 2 is the cheaper source of lime, costing $2,250; whereas source 1 costs $2,625— almost a 25% difference in final costs.

Making It Easy

Calculators are available on the Web site of the University of Kentucky Division of Regulatory Services (http://soils.rs.uky.edu/calculators/) to help make these calculations and comparisons quickly and easily.

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