Chapter 15

LIME AND ITS SOIL-PLANT RELATIONSHIPS

Soil acidity and the nutritional conditions that accompany it result when there is a deficiency of adsorbed metallic cations relative to hydrogen. To increase acidity the hydrogen must be replaced by metallic cations. This is commonly done by adding oxides, hydroxides, or carbonates of calcium and magnesium.

These compounds are referred to as agricultural limes. They are relatively inexpensive, comparatively mild to handle, and leave no objectionable residues in the soil. They are vital to successful agriculture in most humid regions.

15:1. Liming Materials

Oxide of lime. Commercial oxide of lime is normally referred to as burned lime, quicklime, or often simply as the oxide. It is usually in a finely ground state and is marketed in paper bags. Oxide of lime is more caustic than limestones and may be somewhat disagreeable to handle.

Burned lime is produced by heating limestone in large commercial kilns. Carbon dioxide is driven off and the impure calcium and magnesium oxides are left behind. The essential reactions that occur when limestones containing calcite and dolomite are heated are as follows:

\[
\text{CaCO}_3 + \text{heat} \rightarrow \text{CaO} + \text{CO}_2
\]

Calcite

\[
\text{CaMg(CO}_3)_2 + \text{heat} \rightarrow \text{CaO} + \text{MgO} + 2\text{CO}_2
\]

Dolomite

The purity of burned lime sold for agricultural purposes varies from 85 to 98 percent, 95 percent being an average figure. The impurities of burned lime consist of the original impurities of the limestone, such as chert, clay, and iron compounds. In addition to the calcium oxide and magnesium oxides are small amounts of the hydroxides since the oxides readily take up water from the air and slake to some extent even when bagged. Also, contact with the carbon dioxide of the atmosphere will tend to produce carbonates.

Hydroxide of lime. This form of lime is commonly, though improperly, referred to as the hydrate. And since it is produced by adding water to burned lime, the hydroxides that result are often called slaked lime. The reaction is as follows:

\[
\text{CaO} + \text{MgO} + 2\text{H}_2\text{O} \rightarrow \text{Ca(OH)}_2 + \text{Mg(OH)}_2
\]

Hydroxide of lime appears on the market as a white powder and is more caustic than burned lime. Like the oxide, it requires bagging. Representative samples generally show a purity of perhaps 95 or 96 percent.

To maintain the concentration of this form of lime at a high point, the slaking often is not carried to completion. As a result, considerable amounts of the oxides are likely to remain. Moreover, hydroxide of lime carbonates readily. The carbonation of calcium and magnesium hydroxides occurs as follows:

\[
\text{Ca(OH)}_2 + \text{CO}_2 \rightarrow \text{CaCO}_3 + \text{H}_2\text{O}
\]

\[
\text{Mg(OH)}_2 + \text{CO}_2 \rightarrow \text{MgCO}_3 + \text{H}_2\text{O}
\]

Carbonation is likely to occur if the bag is left open and the air is moist. Besides the impurities, six important lime compounds are usually present: the oxides, the hydroxides, and the carbonates of calcium and magnesium. The hydroxides, of course, greatly predominate.

Carbonate of lime. There are a number of sources of carbonate of lime. Of these, pulverized or ground limestone is the most common. There are also bog lime or marl, oyster shells, and precipitated carbonates. Also lime carbonates are by-products of certain industries. All of these forms of lime are variable in their content of calcium and magnesium.

The two important minerals carried by limestones are calcite, which is mostly calcium carbonate \((\text{CaCO}_3)_2\), and dolomite, which is primarily calcium magnesium carbonate \([\text{CaMg(CO}_3)_2]\). These occur in varying proportions. When little or no dolomite is present, the limestone is referred to as calcic. As the magnesium increases, this grades into a dolomitic limestone and, finally, if very little calcium carbonate is present and the stone is almost entirely composed of calcium–magnesium carbonate and impurities, the term dolomite is used. Most of the crushed limestone on the market is calcic and dolomitic, although ground dolomite is available in certain localities.

Ground limestone is effective in increasing crop yields (see Fig. 15:1) and is used to a greater extent than all other forms of lime combined. It varies in purity from approximately 75 to 99 percent. The average purity of the representative crushed limestone is about 94 percent.
FIGURE 15:1. Alfalfa was seeded in this field trial. In the foreground the soil was unlimed (pH 5.2). In the background 4 tons of limestone per acre were applied before seeding.

15:2. CHEMICAL GUARANTEE OF LIMING MATERIALS

Since the various forms of lime are sold on the basis of their chemical composition, the commercial guarantees in this respect become a matter of some importance. The oxide and hydroxide forms may bear composition guarantees stated in one or more of the following ways—the conventional oxide content, the calcium oxide equivalent, the neutralizing power, and percentages of calcium and magnesium. To facilitate the explanation and comparison of the various methods of expression, composition figures for commercial burned and hydroxide of lime are shown in Table 15:1.

CONVENTIONAL OXIDE AND CALCIUM OXIDE EQUIVALENT. Since the oxide form of expression is so commonly used, this type of guarantee is designated here as the conventional method. The calcium oxide equivalent, as the term implies, is a statement of the strength of the lime in one figure, calcium oxide. The magnesium oxide is expressed in terms of calcium oxide equivalent, and this figure is added to the percentage of calcium oxide present. This may be conveniently done by means of conversion factors. Thus, for the commercial oxide of Table 15:1, 18 percent magnesium oxide is equivalent to 25 percent calcium oxide (18 x 1.389 = 25) and 77 + 25 = 102, the calcium oxide equivalent. This means that every 100 pounds of the impure burned lime is equivalent in neutralizing capacity to 102 pounds of pure calcium oxide.

To express one lime in chemically equivalent amounts of another, simply multiply by the appropriate ratio of molecular weights. Thus, the calcium oxide equivalent of magnesium oxide is obtained by multiplying by the molecular ratio of CaO/MgO, or 56/40.3 = 1.389. Other appropriate factors are:

- \( \text{CaCO}_3 \) to \( \text{CaO} \) = 0.560
- \( \text{CaO} \) to \( \text{CaCO}_3 \) = 1.786
- \( \text{MgCO}_3 \) to \( \text{CaO} \) = 0.664
- \( \text{MgCO}_3 \) to \( \text{CaCO}_3 \) = 1.186

NEUTRALIZING POWER AND ELEMENTAL EXPRESSION. The neutralizing power, as the term is arbitrarily used in respect to lime, is nothing more than a statement of its strength in terms of calcium carbonate—it is calcium carbonate equivalent. By multiplying by 1.786 in the case above, the calcium oxide equivalent of 102 becomes 182.1, the calcium carbonate equivalent. This means that every 100 pounds of the impure burned lime is equivalent in neutralizing capacity to 182.1 pounds of pure calcium carbonate.

The elemental method of expression, while not so common as the others, is required by law in some states. It may be readily calculated from the conventional oxide guarantee. Or, if given alone, the other forms of statement may be derived from it.

Commercial limes practically always carry the conventional oxide guarantee and sometimes the elemental. Thus, the amount of magnesium as well as calcium present is indicated. This is an important consideration. In addition, one or even both of the other forms of guarantee may be given.

LIMESTONE GUARANTEES. The guarantees on ground limestone differ in two respects from those of the oxide and hydroxide forms. Usually the separate percentages of calcium and magnesium carbonates are given. These are almost always accompanied by the percentage of total carbonates and sometimes by the neutralizing power. In addition, one or more of the other three modes of
guarantee may be used. By way of illustration the six methods of expression are presented in Table 15:2 for a representative ground limestone.

**TABLE 15:2. Composition of a Representative Commercial Ground Limestone Expressed in Different Ways**

<table>
<thead>
<tr>
<th>Element</th>
<th>Separate Carbonates (%)</th>
<th>Total Carbonates (%)</th>
<th>Neutralizing Power</th>
<th>Conventional Oxide (%)</th>
<th>Conventional Oxide Equivalent</th>
<th>Element (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CaCO₃</td>
<td>80</td>
<td>94</td>
<td>96.6</td>
<td>54.10</td>
<td>Ca = 32.10</td>
<td></td>
</tr>
<tr>
<td>MgCO₃</td>
<td>14</td>
<td>10</td>
<td>6.70</td>
<td>4.11</td>
<td>Mg = 4.03</td>
<td></td>
</tr>
</tbody>
</table>

**TOTAL CARBONATES VERSUS NEUTRALIZING POWER.** The total carbonate method of guarantee has the advantages of being simple and of requiring no chemical explanation. Furthermore, the total carbonates give perhaps a truer indication of the immediate comparative field value of limestones.

Those favoring the neutralizing-power method of expression stress its accuracy and the fact that it can be determined very easily and quickly. It gives a measure of the long-term neutralizing ability of limestones and provides recognition of the higher neutralizing power of the dolomite-containing stones. Since the rate of reaction of dolomite is significantly slower than calcite, however, there is some question as to whether this recognition is appropriate (see Fig. 15:2).

15:3. FINENESS GUARANTEE OF LIMESTONE

The application to the soil of two different liming materials in chemically equivalent quantities does not necessarily mean that equivalent results will be attained. If the two materials are both limestones, the particles contained therein are likely to be quite variable in size as well as hardness. This is important since the finer the division of any material, the more rapid is likely to be its solution and rate of reaction. The oxide and hydroxide of lime usually appear on the market as almost impalpable powders; consequently their fineness is always satisfactory. Therefore, to rate a limestone as to its probable effects in comparison with other limes, a fineness guarantee is desirable. This is usually one of the requirements of laws controlling the sale of agricultural limestone. A mechanical analysis is made by the use of screens of different mesh, a 10-mesh sieve, for example, having ten openings to the linear inch.¹ The proportion of the limestone that will pass through the various screens used constitutes the guarantee.

**INTERPRETATION OF GUARANTEE.** Figure 15:3 shows that the finer grades of limestone are much more effective than the coarser grades in benefiting plant growth. Other data indicate that while the coarser lime is less rapid in its action, it remains in the soil longer and its influence should be effective for a greater period of years. Other investigators have published results that substantiate these conclusions. The proportionate responses are somewhat different, however. This is to be expected since limestones of different hardness applied to various soil types are sure to respond rather diversely.

**FINE LIMESTONE.** Everything considered, a pulverized limestone, all of which will pass a 10-mesh screen, and at least 50 percent of which will pass a

¹ The diameter of the individual openings will, of course, be much less than 0.1 inch, the exact size depending on the wire used in making the sieve. Usually the diameter of the openings in inches is a little more than one-half of the quotient obtained by dividing 1 by the mesh rating. For instance, the openings of a 10-mesh screen are approximately 0.07 in. in diameter; those of a 50-mesh screen, 0.0122 in.; and those of a 100-mesh screen, approximately 0.0058 in. Unfortunately there is no standardization of the sieves used for grading agricultural limestone.
100-mesh sieve, should give excellent results and yet be cheap enough to encourage its use. Such a lime is sufficiently pulverized to rate as a fine limestone. Some limestones are finer than this, 50 or 60 percent passing a 200-mesh screen, but the cost of grinding the stone to this very fine condition seldom can be justified. The fine limestone described above has enough of the finer particles to give quick results and yet a sufficient amount of the coarse fragments to make it last over the period of the rotation.

A limestone which does not approximate the fineness designated above should be discounted to the extent to which it falls short. It may be necessary, for example, to consider 3,000 pounds of one limestone as equal to 1 ton of another, even though their chemical analyses are the same. Considerable judgment in the interpretation of fineness guarantee is necessary in order that such an adjustment be made correctly. Much limestone that falls below the standard set above is now being used because, as a by-product, it is very cheap. When the amounts put on the land are properly adjusted, as good results may be expected from the coarser as from the finer limestones and the effects should last considerably longer.

15:4. CHANGES OF LIME ADDED TO THE SOIL

In considering the changes which lime undergoes after it is added to the soil, we must always keep in mind that (a) the calcium and magnesium compounds applied undergo solution under the influence of a variable partial pressure of carbon dioxide, and (b) an acid colloidal complex will adsorb considerable amounts of calcium and magnesium ions.

**REACTION WITH CARBON DIOXIDE.** When lime—whether the oxide, hydroxide, or the carbonate—is applied to an acid soil, the movement as solution occurs is toward the bicarbonate form. This is because the carbon dioxide partial pressure in the soil, usually several hundred times greater than that in the atmospheric air, generally is high enough to cause a reaction with the hydroxide and even the carbonate. The reactions, written only for the purely calcium limes, follow:

\[
\begin{align*}
\text{CaO} + \text{H}_2\text{O} & \rightarrow \text{Ca(OH)}_2 \\
\text{Ca(OH)}_2 + 2\text{H}_2\text{CO}_3 & \rightarrow \text{Ca(HCO}_3)_2 + 2\text{H}_2\text{O} \\
\text{CaCO}_3 + \text{H}_2\text{CO}_3 & \rightarrow \text{Ca(HCO}_3)_2
\end{align*}
\]

**REACTION WITH SOIL COLLOIDS.** All liming materials will react with acid soils, the calcium and magnesium replacing hydrogen on the colloidal complex. The adsorption in respect to calcium may be indicated as follows:

\[
\begin{align*}
\text{H-Micelle} + \text{Ca(OH)}_2 & \rightleftharpoons \text{Ca-Micelle} + 2\text{H}_2\text{O} \\
\text{H-Micelle} + \text{Ca(HCO}_3)_2 & \rightarrow \text{Ca-Micelle} + 2\text{H}_2\text{O} + 2\text{CO}_2^{1} \\
\text{H-Micelle} + \text{CaCO}_3 & \rightarrow \text{Ca-Micelle} + \text{H}_2\text{O} + \text{CO}_2^{1}
\end{align*}
\]

As the above reactions of limestone proceed, carbon dioxide is freely evolved. In addition, the adsorption of the calcium and magnesium raises the percentage base saturation of the colloidal complex and the pH of the soil solution is pushed up correspondingly.

**DISTRIBUTION OF CALCIUM AND MAGNESIUM IN LIMED SOIL.** Calcium and magnesium, if supplied by a limestone of average fineness, will exist in the soil at least for a time, in three forms: (a) as solid calcium and calcium-magnesium carbonates, (b) as exchangeable bases adsorbed by the colloidal matter, and (c) as dissociated cations in the soil solution mostly in association with bicarbonate ions. When the calcium and calcium-magnesium carbonates have all dissolved, the system becomes somewhat simpler, involving only the exchangeable cations and those in soil solution, both of which are subject to loss by leaching.
DEPLETION OF CALCIUM AND MAGNESIUM. As the soluble calcium and magnesium compounds are removed, the percentage base saturation and pH are gradually reduced and eventually another application of lime is necessary. This then is the type of cycle through which much of the calcium and magnesium added to arable soils swings in humid regions.

15:5. LOSS OF LIME FROM ARABLE SOILS

Calcium and magnesium are lost from soils in three ways: (a) by erosion, (b) by crop removal, and (c) by leaching. Since these three types of lime loss have already been discussed and evaluated in Chapter 9, it is a simple matter to draw such data together in tabular form (Table 15:3). Although the values shown do not represent losses from soils in general, they are quite significant when used comparatively.

TABLE 15:3. Lime Losses from Soil

<table>
<thead>
<tr>
<th>Manner of Removal</th>
<th>Calcium</th>
<th>Magnesium</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CaO</td>
<td>MgO</td>
</tr>
<tr>
<td>By erosion, Missouri experiments, 4 percent slope</td>
<td>120</td>
<td>48</td>
</tr>
<tr>
<td>Total</td>
<td>564</td>
<td>277</td>
</tr>
</tbody>
</table>

The data for erosion removals are for a silt loam in Missouri cropped to a rotation of corn, wheat, and clover (see Table 9:6). The acre annual removal by crops was calculated for a standard and representative rotation, assuming reasonable yields (see Table 9:2). The leaching losses are for a postulated representative silt loam under a rainfall of perhaps 36 to 40 inches and cropped to a standard farm rotation. All data are in pounds per acre per year expressed in the conventional oxide form and also in the more practical terms of calcium and magnesium carbonates.

The greater loss of calcium than magnesium no doubt is because the soil colloidal matter almost always carries a much larger amount of the calcium in an exchangeable condition. And since the average liming material supplies several times more calcium than magnesium, this loss ratio will in general be maintained and even accentuated in arable lands as liming proceeds.

This does not mean, however, that the magnesium in lime is of minor importance. Far from it. In fact, judging from the figures of Table 15:3, there should always be at least one third as much magnesium as calcium in the lime applied in order to proportionately meet the outgo of the two constituents. Other things being equal, it is generally wise to select a magnesium-containing limestone.

The figures quoted in Table 15:3 indicate that 500 to 600 pounds of limestone per acre per year may be required to meet the loss from cropped soils in humid regions. This amounts to about 1 to 1.5 tons of carbonate of lime during the period of the average rotation, depending upon the kind of soil and other factors. Such a conclusion verifies the importance of lime in any scheme of fertility management in areas of medium to heavy rainfall.

15:6. EFFECTS OF LIME ON THE SOIL

It has already been emphasized that the changes of lime in the soil are many and complicated. Therefore, the following presentation must necessarily be more or less general in nature. The better known effects of liming are (a) physical, (b) chemical, and (c) biological.

PHYSICAL EFFECTS. A satisfactory granular structure is somewhat encouraged in an acid soil by the addition of any form of lime, although the influence is largely indirect. For example, the effects of lime upon biotic forces are significant, especially those concerned with the decomposition of the soil organic matter and the synthesis of humus. The genesis of the humus as well as its persistence greatly encourages granulation (see p. 58). The stimulating effect of lime on deep-rooted plants, especially legumes, is significant.

CHEMICAL EFFECTS. If a soil at pH 5.0 is limed to a more suitable pH value of about 6.5, a number of significant chemical changes occur. Many of these were described in Chapter 14 and will be outlined here to reemphasize their importance.

1. The concentration of hydrogen ions will decrease.
2. The concentration of hydroxyl ions will increase.
3. The solubility of iron, aluminum, and manganese will decline.
4. The availability of phosphates and molybdates will increase.
5. The exchangeable calcium and magnesium will increase.
6. The percentage base saturation will increase.
7. The availability of potassium may be increased or decreased depending on conditions.

Of the specific chemical effects of lime mentioned, the reduction in acidity is one commonly recognized. However, the indirect effects on nutrient availability and on the toxicity of certain elements are probably more important. Liming of acid soils enhances the availability and plant uptake of
elements such as molybdenum, phosphorus, calcium, and magnesium. At the same time, it drastically reduces the concentration of iron, aluminum, and manganese, which under very acid conditions are likely to be present in toxic quantities.

**BIOLOGICAL EFFECTS.** Lime stimulates the general purpose, heterotrophic soil organisms. This stimulation not only favors the formation of humus but also encourages the elimination of certain organic intermediate products that might be toxic to higher plants.

Most of the favorable soil organisms, as well as some of the unfavorable ones such as those that produce potato scab, are encouraged by liming. The formation of nitrates and sulfates in soil is markedly speeded up by increasing the pH. The bacteria that fix nitrogen from the air, both nonsymbiotically and in the nodules of legumes, are especially stimulated by the application of lime. The successful growth of most soil microorganisms so definitely depends upon lime that satisfactory biological activities cannot be expected if calcium and magnesium levels are low.

**15:7. CROP RESPONSE TO LIMING**

Figure 14:9 specifies in a general way the lime levels at which various plants seem to grow most satisfactorily, thereby indicating whether or not a particular crop is likely to be benefited by liming. Of the lime-loving plants, alfalfa, sweet clover, red clover, asparagus, cauliflower, and lettuce are representative. However, a surprisingly large proportion of crop plants is quite tolerant to the conditions presented by moderately acid soils. If such plants respond to lime, it is because of the stimulating influence of lime upon the legume which preceded them in the rotation.

**REASONS FOR RESPONSE.** When plants are benefited by lime, a number of possible reasons may be suggested: (a) the direct nutritive or regulatory action of the calcium and magnesium, (b) the removal or neutralization of toxic compounds of either an organic or inorganic nature; (c) the retardation of plant diseases, (d) an increased availability chemically of plant nutrients, and (e) an encouragement of microorganic activities favorable in a nutritive way. Since several of these factors undoubtedly function concurrently, crop response to liming is a complicated phenomenon, and only the broadest conclusions may be drawn.

The growth of a number of plants is definitely retarded by liming, prominent among which are cranberries, blueberries, watermelons, laurel, and certain species of azaleas and rhododendrons. It is, therefore, advantageous not only to know the condition of the soil but also to understand the influence of lime on the crop to be grown. Lime is too often used as a cure-all, little attention being paid to the widely differing responses exhibited by various crops.

**15:8. OVERLIMING**

This leads to the question of overliming, the addition of lime until the pH of the soil is above that required for optimum plant growth on the soil in question. Under such conditions many crops that ordinarily respond to lime are detrimentally affected, especially during the first season following the application. With heavy soils and when only moderate amounts of lime are used, the danger is negligible. But on sandy soils low in organic matter and therefore lightly buffered, it is easy to injure certain crops, even with a relatively moderate application of lime.

The detrimental influences of excess lime have been mentioned (see p. 389). Consequently, they are merely outlined here for convenience:

1. Deficiencies of available iron, manganese, copper, and/or zinc may be induced.
2. Phosphate availability may decrease because of the formation of complex and insoluble calcium phosphates.
3. The absorption of phosphorus by plants and especially its metabolic use may be restricted.
4. The uptake and utilization of boron may be hindered.
5. The drastic change in pH may in itself be detrimental.

With so many possibilities and with such complex biocolloidal interrelations to handle, it is easy to see why overliming damage in many cases has not been satisfactorily explained.

The use of lime in a practical way raises three questions. If the first is answered in the affirmative, the other two present themselves in logical sequence. The three questions are: (a) Shall lime be applied? (b) Which form shall be used? (c) What shall be the rate of application?

**15:9. SHALL LIME BE APPLIED?**

The old concept concerning lime was that of a cure-all—that it was almost certain to be beneficial, no matter what the problem. Such an opinion should now be discarded since it may lead to a waste of money and in some cases to overliming. The use of lime must be based on measured soil acidity and on crop requirements.

In determining the desirability of applying lime, the chemical condition of the soil itself should be examined. For this a pH determination commonly is made, either by means of a pH meter or by the less accurate indicator-dye method (p. 393). Representative subsoil as well as surface samples should be examined. The pH is correlated fairly closely with percentage base saturation and is an indicator of the probable activity of the calcium, magnesium, and other elements in the soil. Besides, the test is very easy and the results are
quickly determined, two reasons why the test is one of the most popular now available for soil diagnosis.

Before a recommendation can be made, however, the general lime need of the crop or crops to be grown should be considered. The final decision depends upon the proper coordination of these two types of information. A grouping of crops such as that shown in Fig. 14:8 will greatly aid in deciding whether or not to lime.

15:10. Form of Lime to Apply

On the basis of the ideas already presented, it is evident that five main factors should be considered in deciding on a specific brand of lime to apply:

1. Chemical guarantees of the limes under consideration.
2. Cost per ton applied to the land.
3. Rate of reaction with soil.
4. Fineness of the limestone.
5. Miscellaneous considerations (handling, storage, bag or bulk, and so on).

Guarantee and Cost Relations. By a purely arithmetical calculation based on factors 1 and 2, the cost of equivalent amounts of lime as applied to the land can be determined. These factors will show which lime will furnish the greatest amount of total neutralizing power for every dollar expended.

For instance, the neutralizing power (CaCO$_3$ equivalent) of two limes, a hydroxide and a ground limestone, are guaranteed at 135 and 95, respectively. The cost of applying a ton of each to the land (all charges, including trucking and spreading) for purposes of calculation will be considered to be $15.00 for the hydroxide and $8.00 for the carbonate. Obviously, it will require only 0.75, or 0.7 ton of the hydroxide to equal 1 ton of the carbonate. The cost of equivalent amounts of neutralizing power based on 1 ton of limestone will therefore be $10.50 for the hydroxide of lime and $8.00 for the limestone. Unless a rapid rate of reaction were desired, the advantage in this case would definitely be with the limestone. Economic considerations account for the fact that about 95 percent of the agricultural liming material applied in the United States is ground limestone.

Rate of Reaction with Soil. Burned and hydrated limes react with the soil much more rapidly than do the carbonate forms. For this reason, these caustic materials may be preferred where immediate reaction with the soil is required. In time, however, this initial advantage is nullified because of the inevitable carbonation of the caustic forms of lime.

In comparing carbonate-containing materials, it should be remembered that highly dolomitic limestones generally react more slowly with the soil than do those which are highly calcic. This difference is due to the comparatively slow rate of reaction of dolomite which is supplied along with calcite in dolomitic limestones (see Fig. 15:2). When rapid rate of reaction is not a factor, however, dolomitic limestone is often preferred because significant quantities of magnesium are supplied by this material. Over a period of two or three rotations, soils treated with highly calcic limestone have been known to develop a magnesium deficiency even though the pH was maintained near 7.

The fineness of the limestones under consideration is important, especially if the material is high in dolomite. If it is not sufficiently pulverized to rate as a fine lime (see the rule on pp. 409-10), allowance must be made for the lack of rapid acting material by increasing the rate of application.

Miscellaneous Factors. Several miscellaneous factors may at times be important. The handling of the caustic limes, even when bagged, is somewhat more disagreeable than working with limestone. The necessity for storage also comes in since sometimes it is desirable to carry lime from one season to another. Limestone has the advantage here since it does not change in storage as the others do.

The question of purchasing the lime, especially the limestone, in bags or in bulk has become increasingly important in recent years. Spreading limestone in bulk by trucks has greatly reduced handling costs (see Fig. 15:4). This method tends, however, to limit the choice of when the material may be applied, since wet or plowed fields cannot be serviced by heavy machinery. The decision as to what method to use should not be finally approved until the nature of the soil and the probable response of the crops have again been reviewed.

15:11. Amounts of Lime to Apply

The amount of lime to apply is affected by a number of factors, including the following:

1. pH.
   - Surface: Texture and structure.
   - Subsoil: pH, texture, and structure.

3. Crops to be grown.
4. Kind and fineness of lime used.
5. Economic returns in relation to cost of lime.

Soil Characteristics. The pH test is invaluable in making decisions because it gives some idea of the percentage base saturation of the soil and the need for lime. The texture and organic matter also are important since they are indicative of the adsorptive capacity of the soil and the strength of...
buffering (see Fig. 15:5). Naturally the higher the buffer capacity of a soil, the greater must be the amount of lime applied to attain a satisfactory change in pH.

The subsoil also should be tested for pH and examined as to texture and structure. A subsoil pH markedly above or below that of the furrow soil may justify a reduction or an increase as the case may be in the acre rate of lime application. Advice as to the cropping of any soil should not be given without knowledge of subsoil conditions.

OTHER CONSIDERATIONS. The other factors listed above have been discussed; besides, their importance is self-evident. As to the kinds of lime, the three forms in respect to their effects on the soil are roughly in the ratio 1 ton of representative finely ground limestone to 0.7 ton of commercial hydroxide to a little over 0.5 ton of representative oxide. The fineness of limestone is as important as chemical composition. The experience factor emphasizes taking advantage of lime knowledge wherever found.

TABLE 15:4. Suggested Total Amounts of Finely Ground Limestone That Should Be Applied per Acre-Furrow Slice of Mineral Soil for Alfalfa in Rotation

<table>
<thead>
<tr>
<th>Need for Lime</th>
<th>Sandy Loam</th>
<th>Silt Loam</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moderate</td>
<td>2,000-3,000</td>
<td>3,000-6,000</td>
</tr>
<tr>
<td>High</td>
<td>3,000-5,000</td>
<td>6,000-8,000</td>
</tr>
</tbody>
</table>

* In calculating these rates, the assumption is made that the amounts suggested will be used as initial applications. After the pH of the soil has been raised to the desired level, smaller maintenance rates may be satisfactory.
15:12. METHODS OF APPLYING LIME

To obtain quick action, lime is best applied to plowed land and worked into the soil as the seedbed is prepared. It should be mixed thoroughly with the surface half of the furrow slice. Top-dressing with lime and leaving it on the surface is seldom recommended except on permanent meadows and pastures.

However, it is often much more convenient and in the long run just as effective to apply the lime on the surface and plow it under. The spreading is usually done in the fall on sod land that is to be turned later that autumn or the next spring. This practice provides a longer interval during which lime may be applied and usually results, in the case of a sod, in a minimum of soil packing if heavy machinery is used. It also makes possible the bulk spreading of lime, using large trucks. This is becoming increasingly popular (see Fig. 15:4).

The time of year at which lime is applied is immaterial, the system of farming, the type of rotation, and related considerations being the deciding factors. Winter application may even be practiced.

EQUIPMENT USED. Limestone is commonly spread in bulk form using large trucks (see Fig. 15:4). A smaller lime distributor may also be used, especially if the amount to be applied is not unusually large. Small amounts of lime may be distributed by means of the fertilizer attachment on a grain drill. The evenness of distribution is as important as the amount of lime used and should not be neglected.

The addition of small amounts of limestone, 300 to 500 pounds per acre, often gives remarkable results when drilled in with the crop being seeded. Even though the lime is not mixed thoroughly with the soil and there is little change in the pH of the furrow slice as a whole, the influence on the crop may be very favorable. Apparently the lime in this case is functioning more as a fertilizer and as a means of rectifying conditions within the crop and at root-soil interfaces than as an amendment for the whole furrow slice.

PLACE IN ROTATION. Lime should be applied with or ahead of the crop that gives the most satisfactory response. Thus, in a rotation of corn, oats, fall wheat, and two years of alfalfa and timothy, the lime is often applied when the wheat is seeded in the fall. It can then be spread on the plowed ground and worked in as the seedbed is prepared. Its effect is thus especially favorable on the new legume seeding made in the wheat.

However, application to plowed land may result in some compaction of the soil if heavy machinery is used and certainly more power is necessary than for a soil in sod. For that reason, spreading on sod land is often favored. In practice, the place of lime in the rotation is often determined by expediency, since the vital consideration is, after all, the application of lime regularly and in conjunction with a suitable rotation of some kind.

15:13. LIME AND SOIL FERTILITY MANAGEMENT

The maintenance of satisfactory soil fertility levels in humid regions is dependent upon the judicious use of lime (see Fig. 15:6). The pH and associated nutritional condition of the soil is determined by the lime level. Furthermore, the heavy use of acid-forming nitrogen-containing fertilizers increases soil acidity, making even more important the maintenance of a favorable lime status in soils.

![Figure 15:6. Important ways by which available calcium and magnesium are supplied and removed from soils. The major losses are through leaching and erosion. These are largely replaced by lime and fertilizer applications. Additions in the latter form are much higher than is generally realized, owing to the large quantities of calcium contained in superphosphates.](image-url)

REFERENCES


IMPORTANCE

Magnesium (Mg) deficiency in grapevines is uncommon in California and usually is confined to a very small area or to a few vines within a vineyard. The deficiency is most prevalent in sandy soils of low cation exchange capacity (low silt, clay, or organic matter content) and also appears on some calcareous (high calcium carbonate content) and slightly sodic (excess sodium) soils.

Young grapevines are more susceptible until their root systems penetrate subsoils higher in Mg. Mg deficiency is also more common in some grape varieties, including Grenache, Peverella, Thompson Seedless, Green Hungarian, Barbera, Malbec, and Gamay.

Some deficiencies have occurred in topsoil fill areas resulting from land leveling. Such topsoils can be low in Mg, especially if they are sandy. Also, the higher proportion of potassium (K) in these topsoils may interfere with Mg uptake.

The literature on plant nutrition contains many references to Mg deficiencies induced by heavy potassium fertilizer applications in vineyards. Although concern about this "antagonism" between Mg and K is occasionally expressed, we know of no K-fertilizer-induced Mg deficiencies in San Joaquin Valley vineyards.

SOIL AVAILABILITY AND UPTAKE

California soils have generally high levels of available Mg, derived from the weathering of various parent minerals including biotite, dolomite, and serpentine. Plants absorb it as the Mg$^{2+}$ ion from the cation exchange complex where, like potassium, it is attached to negatively charged clay particles and organic matter. This absorption takes place from the soil solution or by the mechanism of root contact exchange with soil colloids.

ROLE AND UTILIZATION

Mg is a constituent of chlorophyll and is therefore essential for photosynthesis. Mg also activates many plant enzymes required in growth processes.

Mg is mobile within plants and can be readily translocated from older to younger tissue under conditions of deficiency.

SYMPTOMS AND DIAGNOSIS OF DEFICIENCY

Mg deficiency symptoms begin with chlorosis (yellowing) of basal leaves, usually after midseason, and progress upward to young leaves. The chlorosis begins at or near the leaf edge and moves inward between the primary and secondary veins. (See fig. 5a.) Some border of normal green color remains along the veins; the chlorotic area may become almost creamy-white. The chlorosis is followed by leaf margin burn; the leaves of black varieties characteristically show a reddish border immediately inside the burned perimeter of tissue (fig. 5b).

FERTILIZATION AND RESPONSES TO Mg

The treatment of Mg deficiency is probably not economical in most San Joaquin Valley vineyards. Usually, only a limited number of vines are affected, and the deficiency does not appear until late summer. Even then, only the basal, older leaves are usually affected.

When warranted—that is, when deficiency symptoms appear by midsummer—the correction of Mg deficiency requires a furrow application of 2 to 4 pounds of magnesium sulfate (epsom salts) per vine. As with K, the soil response is slow—up to 2 years for correction.

Foliar treatment requires repeated sprays annually of 4 pounds magnesium sulfate per 100 gallons water. Higher concentrations can cause leaf burn.

Suspected magnesium deficiency symptoms should be verified by laboratory tissue analysis. The symptoms may be easily confused with those of K deficiency.
Magnesium Deficiency Becoming More Common

By Bill Peacock and Pete Christensen

Symptoms of magnesium deficiency have been more common in vineyards in the southern San Joaquin Valley during the past few years. In most cases, symptoms have been mild, limited to a few basal leaves, with no effect on yield or vine growth. In a few cases, symptoms are serious, and correction may be justified. Magnesium deficiency symptoms vary widely in severity from year to year, and the problem is more pronounced on certain soil types.

Magnesium plays at least two important roles. It is an essential part of the chlorophyll molecule, and is therefore necessary to maintain green leaves high in chlorophyll content. It also activates many plant enzymes required in growth processes. Magnesium is mobile within the plant, and under deficient conditions is readily translocated from older to younger tissue. Older, basal leaves show the first signs of chlorosis.

Chlorotic leaf symptoms first appear in May or June, and by late summer these symptoms can be quite distinctive. The chlorosis is characterized by a general yellowing at the leaf edges, progressing between the primary and secondary veins. This chlorosis may become almost creamy white in color. The primary and secondary veins and surrounding tissue of the leaf remain green, creating what is best described as a “Christmas tree” pattern.

In the southern San Joaquin Valley, magnesium deficiency symptoms are nearly always mild, with only a few basal leaves showing symptoms by late summer. These basal leaves are shaded during summer, adding little to the vine’s overall photosynthetic capacity, and yellowing of these leaves is not a great loss.

Symptoms are considered severe when 20 percent or more of the vine’s leaf canopy is chlorotic. This does represent a significant loss of photosynthetic capacity and correction may be necessary to maximize vine growth and yields. However, severe deficiency rarely occurs.

Young grapevines are more susceptible until their root systems penetrate subsoils higher in magnesium. Magnesium deficiency also is more common in some grape varieties, including Thompson seedless, Grenache and Barbera.

Soil magnesium is a moderately leachable nutrient, and, as with calcium, greater amounts are often found in the subsoil than in upper parts of the soil profile, especially on older, highly weathered soils. In Tulare County, magnesium deficiency is more prevalent with vineyards planted on hardpan soils (old alluvium terraces) that are highly leached and weathered. These hardpan soils (alfisols) include the Exeter, San Joaquin, Traver and Madera soil series. Chemical analysis of these soils usually indicates low levels of magnesium and calcium in the upper portion of the profile where most of the root activity occurs and greater concentration of calcium and magnesium deeper in the soil profile where roots are less active. Under irrigated agriculture, leaching and loss from crop removal seems to have further decreased the calcium and magnesium levels in the upper layers of these soils.

High levels of exchangeable potassium or ammonium can interfere with magnesium uptake by crops. This antagonism is a major concern in some Eastern states with low magnesium soils; however, magnesium deficiencies induced by potassium or ammonium fertilizers have not been documented in San Joaquin Valley vineyards. Citrus growers have found that high rates of manure applied annually can induce magnesium deficiency on low magnesium soils, probably by increasing levels of potassium and ammonium relative to magnesium in the upper portion of the soil profile. Also, high sodium in the soil profile may also be antagonistic and lead to magnesium deficiency problems.

The magnesium concentration of soils is easily measured by a laboratory, but it has been difficult to come up with critical levels. It is very difficult to accurately account for subsoil magnesium supply that may be available to the vine.

Exchangeable magnesium normally constitutes from 4 to 20 percent of the cation exchange capacity (CEC) of the soil. The general consensus is that deficiency is likely when the magnesium saturation of the CEC is less than 5 percent, or when the total exchangeable magnesium concentration drops below 25 milligrams of magnesium per kilogram of soil. Also, exchangeable magnesium should be two to three times as high as exchangeable potassium.

Suspected magnesium deficiency symptoms should be verified by laboratory tissue analysis. The symptoms may be easily confused with those of potassium deficiency. In California vineyards, magnesium concentration in petioles usually increases as the growing season progresses. The critical levels shown below are for samples collected at...
bloom; these critical levels become less reliable when leaf petioles are collected later in the season.

### Critical Levels in Leaf Petioles at Bloom Total Magnesium (percentage)

- **Deficient** ................. less than 0.2
- **Questionable** .............. 0.2-0.3
- **Adequate** .................. over 0.3

Most of our southern San Joaquin Valley soils are alkaline in reaction, but in recent years it is not uncommon to find soils that have become acidic. This change in soil reaction has occurred after years of irrigation and fertilization. Acid soil conditions can lead to magnesium deficiency. This is easily corrected by applying and incorporating lime into the soil, thus neutralizing the acid, and adding calcium and magnesium to the base exchange.

A laboratory analysis of the soil will indicate the lime requirement. Generally it takes two to five tons per acre depending on soil texture, depth of correction and initial soil pH. The soil pH should be 5.5 or higher to avoid magnesium deficiency and other problems associated with acidic soil.

Dolomite is the best choice as a liming material where there is both a potential magnesium deficiency and a soil acidity problem. It contains magnesium and calcium carbonate, which neutralizes soil acidity while adding magnesium to the base exchange.

During the drought years, sodium concentration increased in some vineyards (the result of less leaching and the necessity of using poor quality irrigation water). Reducing sodium concentration in the soil profile can help reduce or correct magnesium deficiency. Sodium reclamation requires the addition of a suitable amendment, which a laboratory analysis can determine, and then sufficient leaching to remove the sodium from the root zone.

The treatment of magnesium deficiency is probably not economical in most San Joaquin Valley vineyards. Usually correcting the underlying problems discussed above solves the problem. When a severe deficiency persists (more that 10 to 20 percent of the leaf capacity is chlorotic), then fertilization may be necessary.

When furrow irrigating, magnesium deficiency is corrected by applying two to four pounds of magnesium sulfate (epsom salts) per vine, placed in a deep furrow close to the vine. This would equal about 1000 to 2000 pounds of magnesium sulfate per acre, which is an expensive treatment. Magnesium sulfate is currently priced at about 25 cents a pound. The vine response is usually slow, taking two years for correction, but the treatment is effective for up to eight years. Most of the time only a portion of the vineyard is severely deficient and only that portion requires fertilization.

We speculate that with a drip irrigation system, less magnesium fertilizer would be necessary to correct a deficiency than would be required with furrow irrigation. This is based on comparative research with potassium and other nutrients. We suggest that one-half to one pound of magnesium sulfate per vine (about 250 to 500 pounds per acre) would successfully correct a severe deficiency. Magnesium sulfate can be injected into the drip system, or, when only a small portion of vineyard requires treatment, applied by hand directly beneath each dripper. Magnesium sulfate is very soluble in water, which is helpful when making solutions and injecting material into a drip system.

Foliar sprays can be used for more immediate correction, although treatment will have to be repeated every year. One or more foliar sprays are applied using four pounds magnesium sulfate per 100 gallons water. Higher concentrations can cause leaf burn. Treatments should occur in the spring, using 150 to 250 gallons per acre. Magnesium chelate and commercial foliar sprays containing magnesium are also available. These materials are convenient to apply and should be used following label recommendations. However, their lower magnesium content and higher cost compared to magnesium sulfate should be considered in the decision.

Mild magnesium deficiency has been evident in vineyards for the past few years. Growers have noticed chlorosis of the basal leaves and questioned the seriousness of the symptoms. Research suggests that a mild deficiency does not affect vine growth or yield, and correction is not necessary. However, in rare cases, severe deficiency occurs which requires correction. Usually, there is an underlying soil condition creating the problem, such as soil that has become very acidic or sodic, or high potassium or ammonium concentrations relative to magnesium in the surface of the soil profile. If magnesium fertilization is required, it may be applied to the soil, through drip irrigation, or by foliar sprays.

(Magnesium deficiency includes general yellowing at the leaf edges, progressing between the primary and secondary veins—creating what is described as a "Christmas tree" pattern.)

---

(Bill Peacock is a UC Cooperative Extension farm advisor based in Tulare County, and Pete Christensen is an Extension viticulture specialist based at the Kearney Agricultural Center in Parlier.)

Grape Grower, December 1993
IMPACTANCE

Zinc (Zn) deficiency has been recognized as a problem in California grape production for more than half a century. Known as the little-leaf disease, it was first identified and corrected as a nutrient deficiency by Chandler and his co-workers in the early 1930s.

Zn deficiency, the most widespread micronutrient deficiency of grapes in California, ranks second to nitrogen deficiency in the number of acres involved. An estimated 10 to 20 percent of California vineyards and orchards are affected, and 20,000 or more acres of grapevines show varying degrees of Zn deficiency. It is common in most of the San Joaquin Valley where grapes are grown, rare in the viticultural areas in the north coast counties, and fairly common in vineyards grown in the central coastal region.

SOURCES IN THE SOIL

Zn is found in minute quantities in all soils; sandy soils have the lowest levels. After being weathered from various minerals, Zn is adsorbed by clay particles and by organic matter and is held in an exchangeable condition. Zn levels tend to be higher in surface soils and often accumulate after being released by decomposing leaves and other plant material.

Zn is less available in soils with a pH greater than 6. At lower pH values, the nutrient becomes more soluble and available. Virtually all of the Zn in the soil becomes fixed at pH 9.

Calcereous materials, such as limestone, increase the Zn-fixing capacity of coarse-textured soils. Soils high in organic content and clay soils of high magnesium content are often low in available Zn. Soils high in native phosphate also may fix Zn in an unavailable form.

Deficiency symptoms are commonly found in San Joaquin Valley vineyards grown on sandy soils and on sites previously used for long periods for corrals or poultry houses. Zn deficiency is also common in vineyards grown on sandy soils with vigorous rootstocks, such as Dogridge, Salt Creek, Harmony, and Couderc 1613, where nematode resistance is needed.

Zn deficiency is not usually encountered uniformly across a vineyard, but is found in limited areas such as sand streaks. Areas subject to heavy cuts during land leveling are likely to be deficient in Zn, as are sandy soils that have received repeated, heavy applications of poultry manure for long periods.

Application of high-nitrogen fertilizers may accentuate zinc deficiency, because nitrogen stimulates total vine growth and thereby increases the Zn needs beyond the available supply. Likewise, vigorously growing young vines, especially in their second year, commonly show temporary and usually mild Zn deficiency due to rapid growth and a still limited root system.

Zn deficiency is very common where grapevine cuttings are planted in methyl-bromide-fumigated soils, such as in nurseries. This results from the temporary reduction of the mycorrhizal fungi population, which assists roots in the uptake of certain nutrients, including Zn and phosphorus.

ROLE AND UTILIZATION

Zn is needed for auxin formation, for the elongation of internodes, and in the formation of chloroplasts (chlorophyll-containing bodies) and starch. In grapes, Zn is essential to normal leaf development, shoot elongation, pollen development, and the set of fully developed berries.

DIAGNOSIS OF DEFICIENCY

Symptoms

Foliage. Deficiency symptoms may vary, depending on the degree of the shortage and on the grape variety. Foliar symptoms of mottling usually appear in early summer at about the time that lateral shoot growth is well developed. The new growth on both the primary and secondary shoots has smaller, somewhat distorted leaves, with a chlorotic pattern exposing the veins as a darker green color. Even the small veinlets retain a uniform-width border of green unless the deficiency is quite severe.

In contrast to normal leaves, which have a deep sinus or cleft where the petiole is attached to the blade, severely affected leaves have undeveloped