Liming Reduces ALUMINUM AND MANGANESE TOXICITY *In Acid Soils*

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Studies of the interaction of nutrients and toxic substances in soils of different acidity levels have shown that liming will raise the pH, increase the calcium supply and lower toxic levels of manganese and aluminum to tolerable amounts. When the pH of soil reaches 5.5, water soluble manganese is increased as compared with more alkaline soils. As the pH approaches 5.0, aluminum toxicity enters the picture. The amount of lime added should be regulated since an excess can induce deficiencies of iron, magnesium and other nutrients.

MOST PLANTS of economic value can make satisfactory growth over a soil pH range between 5.5 and 7.5. The critical zone for alkalinity usually occurs somewhere between a pH of 7.5 and 8.0, but sharp lines cannot be drawn because of the effect of such factors as the presence of lime or neutral salts, differences in sensitivity among the various plant species and the percentage of sodium in the soil. Many of California's high pH soils are found in the San Joaquin and Sacramento valleys, and in some of the smaller valleys, especially in regions of low rainfall and poor drainage.

The point of separation between tolerable and excessive soil acidity is usually between a pH of 5.0 and 5.5. As the pH drops below 5, the problems created by excessive acidity multiply rapidly and must be corrected. Usually a soil pH range between 5.5 and 7.5 is suitable for growing most plants.

The more acid soils occur naturally in areas of high rainfall such as the northern coastal counties of California and the higher altitudes of the Sierra Nevada and Coast ranges. High soil acidity may also be induced, deliberately or inadvertently, by the use of such soil amendments or fertilizers as sulfur, aluminum sulfate, ferric sulfate, and ammonium sulfate. These materials are used to increase the acidity of soil for controlling potato scab, or creating a soil environment for acid-loving plants such as azaleas and rhododendrons. However, even these plants don't grow well if the pH is dropped too far.

Hydrogen ions present in acid soils reduce nutrient uptake and plant growth. This effect has been demonstrated in carefully controlled studies using nutrient solutions. At the same time, it has been observed that these effects of acidity are greater in soil than in a water culture medium with the same pH. This led to the search for other toxic factors in soil, caused by the high acidity.

Toxic factors

Numerous studies have shown that acid soils, besides having a lower pH, are low in bases like calcium, magnesium, and potassium; deficient in phosphorus; and high in iron, manganese and aluminum. Appraising the influence of any one of these elements on plant growth is difficult because a change in one element induces a change in one or more of the others. For example, when lime is added to an acid soil, the pH is raised, and with suitable fertilization, plant growth is improved. However, in addition to a higher pH, the soil now has more base elements; less soluble iron, manganese and aluminum; and possibly more available phosphate. The effect of each of these nutrients or toxic substances on plant growth must be determined in a system where they are all interacting.

CHEMICAL CHANGES IN SOIL EXTRACTS DUE TO LIMING AN ACID SOIL

		− Lime	+ Lime
pH		4.0	5.0
Calcium	m.e. per liter	1.0	6.0
Magnesium	m.e. per liter	1.4	0.7
Potassium	m.e. per liter	0.4	0.1
Iron	ppm	0.1	0.1
Aluminum	ppm	6.4	0.2
Manganese	ppm	16.0	7.8

One approach for measuring these various effects of liming has been to make water extracts of acid soils before and after liming and to analyze these extracts for their constituents. On the basis of these results, artificial nutrient solutions can be prepared for growing plants. By adding or omitting one substance at a time, the influence of each substance can be estimated. Even better is the technique of growing plants in soil extracts themselves without the complications imposed by the presence of soil. This system, however, requires substantial amounts of soil to yield the volume of extract needed to grow plants over an extended period.

The table gives the results of a chemical analysis of two solutions displaced from samples of an acid soil. The first sample was left untreated; the second was limed, and allowed to incubate for 48 hours before the solution was made. The effect of liming was to raise the pH, increase the

Barley, left, and lettuce plants, right, grown in 45-liter tanks containing solutions prepared on the basis of soil extract analysis. Tanks containing aluminum and/or manganese were maintained at pH 4.0 with acid or base as needed.

calcium supply, and lower the manganese and aluminum. The solutions were further analyzed for nitrogen, phosphorus, potash, sulfur, and magnesium. The amounts of iron found were not unusually high in either solution.

Artificial culture

An artificial culture was prepared containing the essential nutrients found in the analysis of the acid soil solution. Similar solutions were prepared in which aluminum or manganese was included, and one in which the pH was maintained at a value of 5.0 by adding sodium hydroxide. Lettuce and barley were grown for 4 weeks in painted iron tanks containing 45 liters of these solutions. The results are shown in the photographs.

In the case of barley a difference of pH from 5 to 4 depressed growth slightly, and the inclusion of manganese depressed it still further. The most pronounced effect on barley growth was due to aluminum, which produced a chlorosis on the old leaves; limited, distorted root growth; and intense root discoloration. On the other hand, manganese showed no effect on the roots aside from reduced growth, but it did produce a large number of small, brown leaf spots, especially on the older leaves. Where aluminum and manganese were added together, the effect was similar to aluminum injury.

The lettuce plants were more sensitive than barley to the drop in pH from 5 to 4. Manganese reduced growth still further, and aluminum resulted in practically no growth at all. The only signs of manganese toxicity in the lettuce were yellowish margins appearing on the borders of the leaves. The plants injured by aluminum showed distortion and discoloration of the roots, and chlorosis of the older, dwarfed leaves.

MANGANESE CONTENT OF LETTUCE AND BARLEY LEAVES SHOWING MANGANESE TOXICITY SYMPTOMS

	BARLEY		LETTUCE	
	Healthy plants	Plants with symptoms	Healthy plants	Plants with symptoms
	Manganese in ppm			
Young leaves....	25	120	80	730
Old leaves......	100	400*	345	2,375*

* Symptoms appeared in old leaves primarily.

These plants were grown in solutions simulating acid soil solutions. If this soil had been previously limed, it would have been higher in pH and calcium, and much lower in aluminum and manganese. Thus, liming soils which are too acid has the double benefit of decreasing acidity and reducing the harmful quantities of aluminum and manganese accompanying high acid content. Of even greater benefit would be the addition of dolomite which adds roughly 1 part of magnesium for every 2 of calcium.

The amount of potassium in acid soil should be checked since soils which have been leached enough to cause high acidity are likely to be low in all bases. Phosphorus is usually deficient in acid soils because it has been leached out. Moreover, phosphate-fixation occurs in some of these soils because the prevalent aluminum immobilizes substantial amounts of phosphate added as fertilizer.

Soil acidity can be measured easily, quickly, and accurately by means of the glass-electrode pH meter which is standard equipment in analytical laboratories. A soil with a pH of 5.5 or lower should be examined more closely for possible toxicity. Leaf symptoms—small brown spots on barley leaves or a yellowish margin on the leaves of lettuce and similar leafy plants—may also indicate acid soil toxicity. A buildup of manganese in the leaf tissues of plants may also suggest excessive soil acidity. Some examples of the manganese content found in leaves of lettuce and barley with and without symptoms are given in the table. Unfortunately, similar data cannot be given for aluminum toxicity because the aluminum uptake by plants has not been closely correlated with the degree of acidity. Because aluminum occurs in different forms, depending on the pH, some of it can be absorbed without having a deleterious effect on plant growth.

Plant sensitivity

Experience in field and greenhouse work has established the sensitivity of various plants to soil acidity. The small group of plants tolerant of high acidity includes raspberries, strawberries, blueberries, cranberries, azaleas, rhododendrons, and a few others. A partial list of plants tolerant of moderate acidity includes barley, beans, flax, corn, oats, wheat, soybeans, potatoes, white clover, subterranean clover, alsike clover, and tomatoes. Among the plants relatively sensitive to acid soil conditions are alfalfa, sweet clover, red clover, onions, red beets, sugar beets, celery, lettuce and spinach.

The amount of lime to be added to an acid soil depends on the initial pH, the kind and amount of clay present, and the final pH desired. Too much lime should be avoided because it produces deficiencies in iron, magnesium, and other nutrients. An analysis of soil which has been limed and incubated for a few days will give a firm estimate of the rate of lime to be used to reach a given pH value. Lime should be mixed with the soil to the expected depth of plant roots because, unlike more soluble fertilizers, it will not penetrate if applied on or near the surface. In most cases the lime added will last for several years before the losses due to plant removal and leaching will have to be replenished.

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