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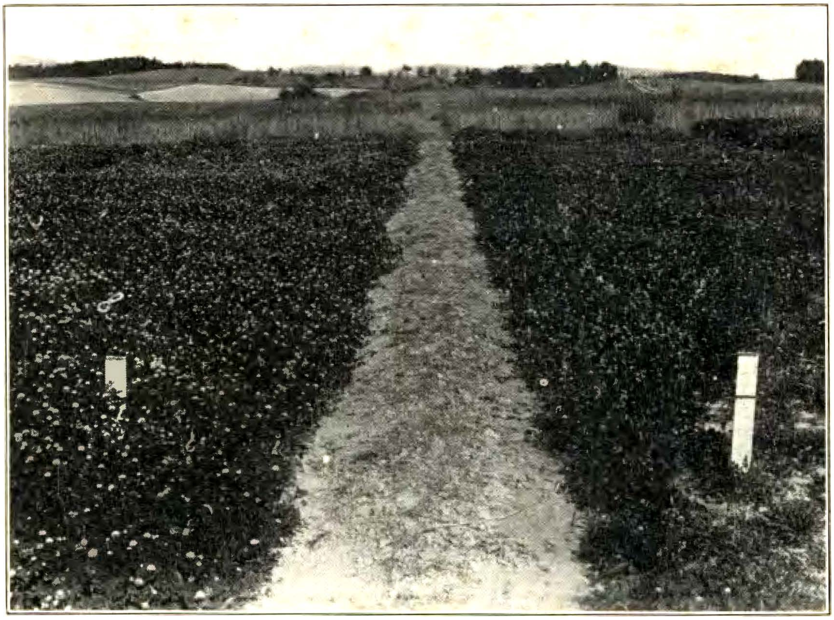
A Useful Chart

For Teaching The Relation of Soil Reaction to The Availability of Plant Nutrients to Crops



Better crops after liming may be due as much to improved plant food availability as to the lime itself.

Virginia Agricultural and Mechanical College and Polytechnic Institute and the
United States Department of Agriculture, Cooperating.
Extension Division, John R. Hutcheson, Director
Blacksburg, Virginia

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A Useful Chart for Teaching the Relation of Soil Reaction to the Availability of Plant Nutrients to Crops

N. A. Pettinger, *Associate Agronomist,*
Virginia Agricultural Experiment Station

The effect of the degree of acidity or alkalinity on the availability[1] of plant foods, or the relation between lime and fertilizers, is one of the most widely discussed subjects in agriculture. It is a subject which holds the interest of farmers, field agents, extension workers, and investigators alike. It is of interest to the grain and livestock farmer, to the vegetable grower, to the lime and fertilizer industries, and occasionally to the golfer and others. It is a subject about which a great deal of information has been accumulated, yet many phases of the problem are not well understood. It is a subject which contains a number of well established and teachable facts, yet these facts are often taught either poorly or not at all. It is a subject which is difficult to present satisfactorily, yet it seldom fails to create a great deal of interest and discussion. It is a subject which must be studied further by scientists, but the facts now available should be given wider dissemination and clearer explanation by teachers, extension workers and field agents.

Many changes take place when a soil becomes acid or when it is limed. Some of these changes are of the utmost importance to the farmer, others are of lesser importance, while still others are of practically no importance at all. The degree to which a soil has become acid or alkaline will in many cases determine the use which crops will be able to make of the supply of plant foods in the soil. The state of reaction markedly affects the availability to crops of some of the usual fertilizer constituents; others are affected but mildly by the reaction. In some cases the availability of plant foods is affected more

[1]The term "availability" is necessarily used in its broadest sense in this paper. It embraces proper utilization within the plant and all of its antecedent processes. As used here, therefore, nutrient availability may involve either wholly or in part the processes of solution, ionization, adsorption, membrane permeability, ion antagonism and balance, assimilation, and many others.

by the conditions created by acidity or alkalinity than by the reaction itself. Whether the effect of reaction is direct or indirect, however, is of secondary importance to the farmer. The important fact is that there is a *change* in the availability of plant foods to the crop as the soil reaction changes. If the prevailing reaction is known, a great deal of other information about the remainder of the soil system automatically becomes known, because of the close association between soil reaction and certain soil conditions. Hence, the state of reaction may be thought of as one of the "pulses" which indicates the "state of health" of the soil, in the same sense that the temperature of the body is an indicator of the state of health in animals. Certain variations in the temperature of the body occur under conditions of normal health, but if the temperature becomes either higher or lower than these limits, the animal is not well. In soils, assuming other factors to be favorable for the growing of crops, a certain range in reaction indicates that the soil is "well," but beyond this range the state of health is not good. As the state of health is good or bad, soil conditions for the availability of plant nutrients will be favorable or unfavorable, respectively. Soil reaction may, therefore, indicate whether the farmer may expect an efficient use of the fertilizer he applies to the soil, or whether much of the plant food added will be lost to the crop because soil conditions are not suitable for keeping the nutrients in forms that are usable by plants. The importance of soil reaction is therefore obvious, and its relation to liming and fertilizing crops is a matter that deserves not only a great deal of study and thought, but wider dissemination and clearer presentation.

The information available on this subject is so widely scattered and much of it so well buried in technical literature that it has not been readily accessible to extension workers and field agents. The technical nature of much of the information has also militated against it in the hands of many people who contact farmers. In order to give this important subject wider and clearer presentation, it seems desirable to attempt a summary and simplification of the facts as they are known at the present time, and to make an effort to present the story in such a way as to interest the non-technical groups in agriculture.

The Color Chart

The chart is composed of a series of bands of color representing the availbility of the various plant foods superimposed on a background which illustrates soil reaction. The changes in width of the color bands represent changes in the availability of the different plant foods to crops over the range of soil reaction shown by the scale in the background. As the bands become narrower the nutrients are less available and as they become wider the availability is increased. The chart has been reproduced in colors to attract and hold attention, and to make it easier to follow the changes that take place.

As now constructed, the chart has certain limitations which should be borne in mind by its user and readily acknowledged. When the work of designing the chart was first undertaken, it was hoped that the bands could be drawn so that their respective widths would represent the relative quantities of the various nutrients available to crops in the average soil. It was soon found, however, that this would be impossible. The quantities of phosphates, manganese and iron available to plants are usually so small in comparison with calcium, magnesium, and potassium, that the idea of proportionate representation had to be abandoned; hence, the difference in the widths of the various bands have no significance when compared with each other. The important feature is the changes in width within the bands.

A second limitation is the fact that the chart is designed to illustrate only the changes which take place in well-drained mineral soils of the humid regions. No claims are made for its applications to the alkali soils of semi-arid regions nor to swampy or highly organic soils, although many of the relations shown may apply wholly or in part to some of these soils also. Furthermore, it cannot be guaranteed that the facts as represented in the chart will apply to any particular soil that may be selected. The changes indicated may be very mild and relatively unimportant in some soils, but in others they may be larger and of great practical importance. The chart is designed to illustrate basic principles involved in the availability of plant foods as associated with changes in soil reaction, rather than to portray the situation in a quantitative or absolute manner for any particular soil.

The demonstrator of the chart should guard against leaving the impression that all of the changes in plant food availability are caused by the changes in soil reaction. They are not. In some cases the degree of availability is determined directly by soil reaction, but in other cases availability is controlled largely by other processes which may or may not be related to soil reaction. In cases where changes in availability follow changes in soil reaction, but in which the evidence is not clear that availability is a function of reaction, the relationship should be referred to as one of *association* rather than as one of cause and effect.

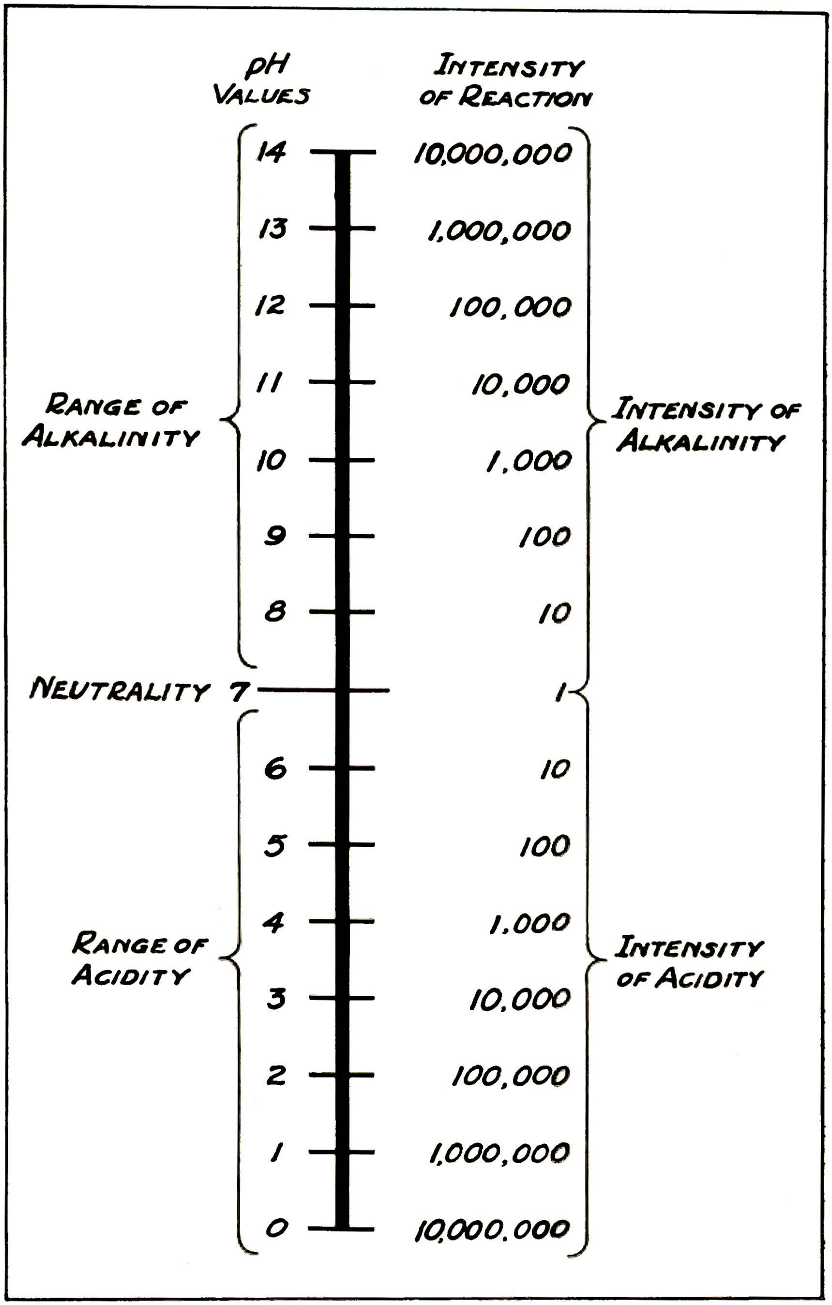
pH
Values
Intensity
of Reaction
14
10,000,000
13
1,000,000
12
100,000
11
10,000
Range of
Alkalinity
10
1,000
Intensity of
Alkalinity
9
100
8
10
Neutrality 7
1
6
10
5
100
4
1,000
Range of
Acidity
3
10,000
Intensity
of Acidity
2
100,000
1
1,000,000
0
10,000,000

Figure 1

Not all of the ideas represented in the chart meet with universal approval. Some investigators contend that in certain cases the trends of availability are somewhat different from those shown on the chart. Nevertheless, as now constructed, the chart represents the facts as shown by a majority of the evidence available and is the consensus of opinions expressed by a number of authorities whose judgement on the subject has been solicited. When the discovery of new evidence makes it necessary to discard present beliefs either wholly or in part, or when better methods of representing the facts are developed, the chart will be revised and re-issued in improved form.

Soil Reaction and the Meaning of pH

Soils, like many other things, are either acid, neutral, or alkaline (basic) in reaction. They become acid when there is an excess of acidic materials over those which are basic. They become alkaline when there is an excess of basic constituents over those which are acidic. When the acidic and basic materials are present in equal[2] proportions, the soil is neither acid nor alkaline and is said to be neutral.

The modern method of measuring and expressing degrees of acidity or alkalinity in soils is in terms of pH values, very much like heat and cold are expressed in degrees Centigrade or Fahrenheit. The Centigrade temperature scale is centered around zero degree or the freezing point of water, and thermometers are used to measure intensities of heat and cold above and below this point. The scale for measuring acidity and alkalinity contains 14 divisions known as pH units. It is centered around pH 7, which is neutral. Values from 7 down to zero constitute the acid range of the scale; values from 7 to 14 make up the alkaline range. These relations are shown graphically in Figure 1.

From this it might be inferred that the acidity values below pH 7 measure the total amount of excess acid constituents and that the values above pH 7 measure the excess alkaline constituents. However, this is not the case. Two acid soils having the same pH value, one a clay and the other a sand, will require widely different amounts of lime for neutralization. It happens that the acid and alkaline materials exist in two forms, namely, (1) free[3] and (2) combined[4]. The former is always small compared to the latter. The pH scale

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[2]Equivalent.

[3]Ionized H^+ and OH^-

[4]Molecular H^+ and OH^-. Hydrogen in mineral and organic acids, acid salts, and hydrogen clays and humates. Hydroxyl ions in hydroxides.

measures only that portion of the excess acid or alkali which is in the free form. It gives no indication of the amount of combined acids or alkalies. The acidity scale below pH 7 is therefore a measure of the *intensity* of acidity rather than the *quantity*, and the scale above pH 7 measures the *intensity* of alkalinity rather than the quantity of excess alkalies.

As shown in Figure 1 and in the accompanying color chart, the intensity of acidity increases *tenfold* with each unit decrease in pH below pH 7. Thus the free acidity is 10 times more intense at pH 6 than at pH 7, 10 times more intense at pH 5 than at pH 6, and so on. The intensity of acidity at pH 5 is therefore 10 x 10 or 100 times the intensity at pH 7, and the intensity at pH 4 is 10 x 10 x 10 or 1,000 times that at pH 7. These tenfold increases in the intensity of free acidity are shown in the left half of the color chart by the portion in red. The blue colored portion in the right half of the chart indicates the same relations with reference to alkalinity. In this case there is a tenfold increase in the intensity of the free alkaline materials with each unit increase in pH above pH 7.

The pH Range of Soils

Most mineral soils are acid in reaction in regions where the rainfall is ample for crops. The reason for this is that the soil retains certain acidic constituents while the basic materials are being removed by leaching and by cropping. The acidity of mineral soils in humid regions is usually between pH 5 and pH 6. In some cases the acidity is below pH 5, but rarely goes as low as pH 4. Acidities between pH 6 and 7 are not uncommon, especially where lime has been applied in recent years. Neutral or slightly alkaline soils are seldom encountered and are found only where large quantities of lime have been applied very recently or where marl or other lime deposits are located near the surface. In the latter case the soil may have an alkalinity of the order of pH 8.

Under arid conditions, soils are predominantly alkaline. The pH is usually between 7 and 8, although alkalinities between pH 8 and 9 are not uncommon. Alkalinities above pH 9 have been observed in soils but are exceptionally rare.

The Availability of Nitrogen

Nearly all plants absorb the bulk of their nitrogen in the form of nitrates. A few crops are known to make some use of ammonia nitrogen in their earlier stages of growth, but under field conditions the quantity used by crops in this form is small compared to the amount of nitrogen absorbed as nitrates. There are, of course, many other forms of nitrogen present in soils, but crops apparently make very little use of them.

Over the usual pH range in soils, nitrates are apparently as available to plants at one pH value as at another.[5] Hence, in special cases where crops receive all of their nitrogen from nitrate fertilizers, soil reaction probably exerts no appreciable influence on the availability of the nitrogen supply.

However, very few crops receive all of their nitrogen in the nitrate form. Practically all of them must obtain all or a part of their nitrogen from the soil organic matter, stable manures, ammonia fertilizers, urea, cyanamid, or such organic fertilizers as cottonseed meal, tankage, fish meal or scraps, etc. The nitrogen in these materials is almost entirely unavailable to plants and must be changed to the nitrate form before it can be used by crops. This conversion is accomplished by microscopic organisms which live in the soil, and of which bacteria are the most important group. Since bacteria are living organisms they are affected adversely by much the same conditions that influence crops unfavorably, and are aided and encouraged by the same conditions which favor and stimulate the growth of crops. Therefore, when conditions are unfavorable for the activity of bacteria, the organic materials are not readily decomposed, and the nitrogen is not converted to the nitrate form. When conditions are favorable to them, the bacteria decompose the organic matter more readily, the nitrogen is transformed into nitrates, and the crop receives the benefit of an available supply of nitrogen.

In acid soils nitrate formation is markedly reduced below pH 5.5. This is indicated on the color chart by a narrowing of the band labeled "nitrates." Above pH 5.5, other conditions being favorable, nitrate formation proceeds quite favorably until an over-supply of lime again reduces the activity of the bacteria. In humid-region soils the harmful effect of too much lime on nitrate formation is seldom experienced.

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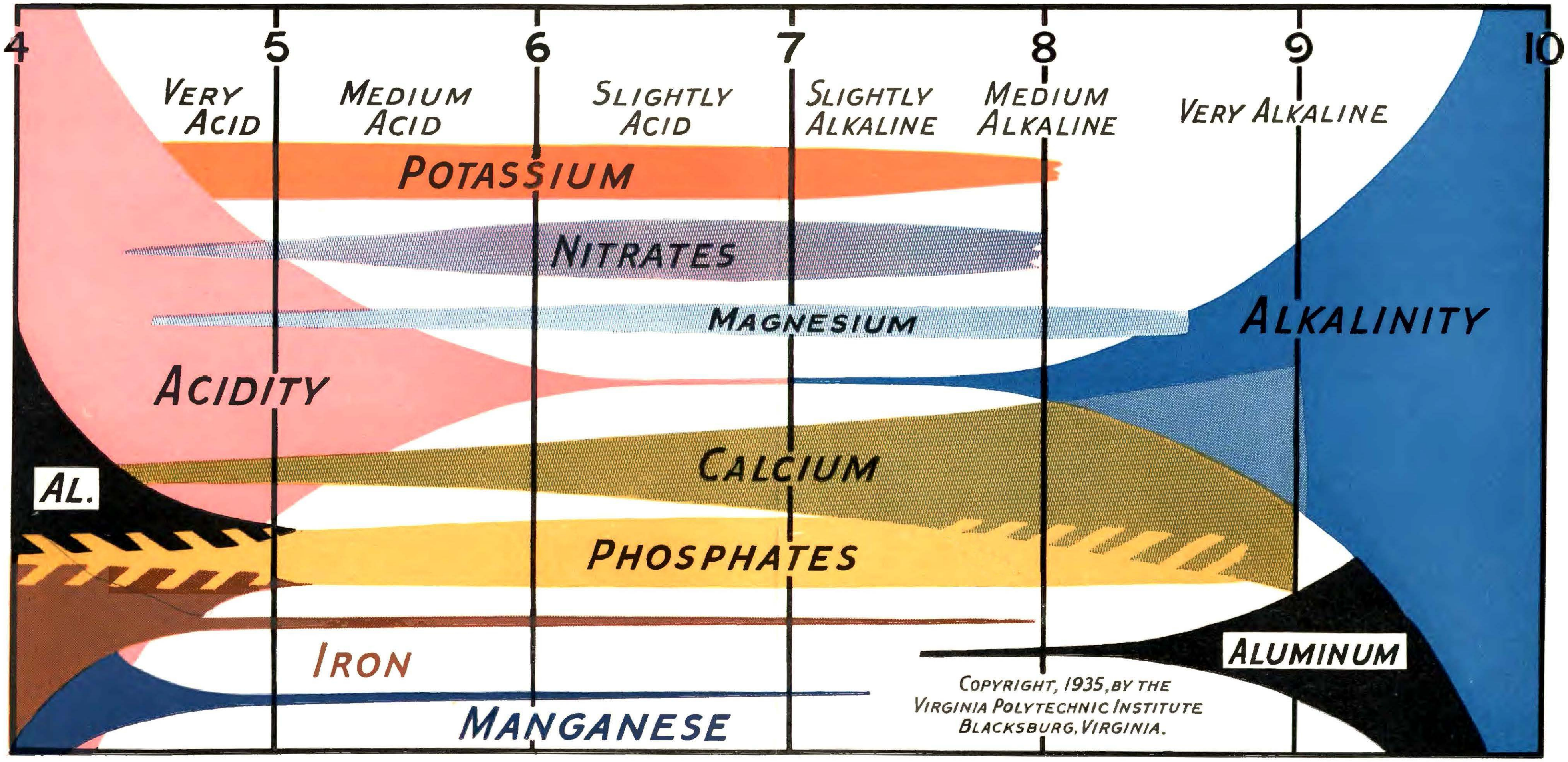
[5]At extremely acid reactions nitrates are absorbed more readily than ammonia nitrogen, but at alkaline reactions ammonia nitrogen is absorbed more readily than nitrates. The reason for this is that when the acidity is high the abundance of H^+ over OH^- ions causes the root membranes to be predominantly electropositive and the passage of electronegative nitrogen (NO_3^-) is easier than that of electropositive nitrogen (NH_4^+). At alkaline reactions, the excess of OH^- over H^+ ions makes the root membranes predominantly electronegative and the passage of electropositive nitrogen (NH_4^+) is easier than that of electronegative nitrogen (NO_3^-).



A large lecture size, 36″ x 72″, of this same chart, on 80-pound offset paper, may be obtained by writing to the Office of Publications, V. P. I., Blacksburg, Virginia, and enclosing $1.00 to cover cost of printing and mailing.

Availability of Phosphates

Cultivated soils are usually more deficient in phosphates than in any other plant food. Where it has become necessary to apply commercial plant foods, phosphates are usually the first to be added. Hence, anything which affects the availability of phosphates in soils is of tremendous importance. Processes which decrease their availability to crops must be viewed with alarm and reduced to a minimum. Processes which increase the availability of phosphates should be looked upon with favor and encouraged as much as possible.

Experiments have shown that soil reaction has a very pronounced effect on the availability of phosphates to crops. It has been found that phosphates are most available between pH 5.5 and pH 7.5. Above and below this range phosphates are partially fixed by other materials which reduce their availability to crops. Below pH 5.5 the fixation is thought to be accomplished largely by aluminum and iron, probably to a greater degree by aluminum than by iron. These two materials are relatively insoluble between pH 5.5 and pH 7.5, but below pH 5.5 they are more soluble. Their solubility is still low, however, until the pH drops to about 4.8 or 5.0, when they come into solution abundantly. As the iron and aluminum come into solution, there is a tendency for them to unite with the phosphates to form iron phosphate and aluminum phosphate. These iron and aluminum phosphates are considered to be unavailable to crops, and their presence really indicates that phosphates which were once available to crops have been converted to a form in which crops are not able to make use of them. Hence, the inferior growth which plants often make on very acid soils may be due as much to phosphate starvation as to any other cause.

Above pH 7.5 phosphates again become less available, but for a different reason. Aluminum comes into solution again above pH 7.5 in increasing quantities, but in the alkaline range it is not able to fix phosphates as it did in the acid range. It is thought that the availability of phosphates is reduced in over-limed soils by the high calcium content. However, the way in which this is accomplished is not definitely known. Recent experiments have shown that the phosphates in over-limed soils are still in solution and therefore presumably available, but that plants are unable to absorb them.

In the accompanying color chart the available phosphates are shown by the solid yellow band. The fixation of phosphates by aluminum is shown by alternate bands of yellow and black thus indicating the formation of the unavailable aluminum phosphate. The fixation by iron is shown by the alternate bands of yellow and brown, indicating the union of iron and phosphate to form the unavailable iron phosphate. In the alkaline range, the reduction in phosphate availability is shown by alternate bands of the colors representing phosphates and calcium.

The Toxicity of Aluminum

When the acidity becomes very high in some soils, more aluminum is brought into solution than is used in the fixation of phosphates. Many investigators believe that this free aluminum is very toxic to the roots of plants, and that it is one of the contributing factors in causing the poor development of crops in very acid soils. In a few soils toxicities have resulted from excess quantities of manganese being thrown into solution when the pH value becomes quite low.

Availability of Potassium

Very little is known concerning the relative availability of potassium to crops in humid soils of different pH values. Some evidence has been accumulated which indicates that in soils which have been limed heavily, potassium is somewhat less available than where liming has been light or moderate. There is no conclusive evidence available concerning the relative changes in the availability of potassium in acid soils, but many agronomists believe that there is very little change in availability in the usual acid range of soils.

Very acid soils have often been observed to be deficient in available potassium. However, this is usually due to continued removal by cropping and leaching and in some cases to erosion, which means that the deficiency was one of *supply* instead of availability. When available potassium is added to such soils, it apparently remains in a form available to crops.

The Available Supply of Calcium and Magnesium

It is often presumed by the layman that acid soils are totally devoid of basic elements. If this were true, crops would not be able to grow on soils below pH 7. Calcium, magnesium and potassium are the principal basic elements in soils which are known to be essential to the growth of plants, and the large yields which crops often make on soils of medium or slight acidity is conclusive evidence that the necessary basic materials are present. Of these three elements potassium is available in smallest quantity, and since the availability of this element has already been discussed, the present chapter deals only with the supply of available calcium and magnesium.

Calcium is the principal constituent of importance in liming materials. It is usually considered synonymously with lime, and in practical circles is usually referred to as lime. Even where dolomitic lime is used to introduce magnesium, calcium is brought in in relatively large quantities. Liming would therefore be expected to increase the supply of available calcium, to reduce acidity (or increase alkalinity), and raise the pH value. The accompanying chart shows this to be the case. The quantity of calcium available to crops in very acid soils is extremely small, but increases sharply with increases in pH. There is approximately twice as much calcium available at pH 4.5 as at pH 4, and twice as much at pH 5 as at pH 4.5. Above pH 5, however, the increase is less rapid. The calcium available at pH 5 is usually not doubled until pH 6 is reached; at pH 7 the quantity is slightly less than double that at pH 6, and at pH 8 the increase is only about 50 percent over the quantity available at pH 7. Hence, the quantity of calcium available in the average soil at pH 4, 5, 6, 7, and 8 is relatively as 1:4:8:14:22, respectively.

The quantity of magnesium available to crops is usually much smaller than the quantity of calcium available. Its relative abundance at different pH values, however, is similar to that of calcium. The quantity available at very acid reactions is exceedingly small, but increases gradually with increases in pH until pH 7.5 is reached, above which a decrease usually occurs. A large number of experiments show that in the average soil the quantity of magnesium available to crops at pH 4.5, 5.5, 6.5, 7.5, and 8.5 is relatively as 1:2:3:4: 2½, respetcively. The rate of increase for magnesium over the pH range of soils is therefore much smaller than for calcium.

In very acid soils the quantity of available calcium and magnesium is often too small for a satisfactory growth of crops, and is unquestionably one of the factors contributing to the poor growth of crops on such soils. Calcium deficiencies are often unobserved because of the lack of definite symptoms in the growing plants, but acute deficiencies of magnesium are sometimes observed in sandy soils by a failure of the plants to develop normally the green coloring matter in their leaves. "Sand drown" of tobacco, "streaking" in the leaves of corn[6], and chlorosis of potatoes and other plants are sometimes evidences of insufficient available magnesium.[7] These troubles usually occur in very acid sandy soils where the basic constituents have been reduced to a low level by cropping and by excessive leaching. A few crops, such as watermelons, cranberries and strawberries, apparently require very little basic materials and make a satisfactory growth at low pH values. Potatoes and tomatoes are also usually grown at relatively acid reactions, but this is done to help control diseases which are aided by lime. Most crops, however, require at least a fair supply of basic elements and make their best growth when the soil is only slightly acid. Some of the leguminous crops like alfalfa and sweet clover prefer large quantities of available calcium, and soils are usually limed to near neutrality where these crops are to be grown.

The Availability of Manganese and Iron

Definite information concerning factors which influence the availability of manganese and iron to plants is still rather fragmentary. Soil reaction is undoubtedly one of the factors affecting the availability of these plant foods. Experiments indicate, however, that the air and water content of the soil, the degree of compactness, the crop to be grown, and the organic matter content of the soil are also important factors. Hence, the type of agriculture practiced, the weather conditions prevailing, and cultural practices employed may all have similar or opposite effects at the same time or at different times. Therefore, the situation with reference to the availability of these two elements may be and usually is comparatively complex.

A few general facts, however, have been rather well established concerning the relative abundance of manganese and iron available to plants at different reactions. The first fact to be borne in mind is that plants require only

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[6]This symptom must be used with caution in diagnosing magnesium deficiencies because a number of "streakings" in corn leaves have been traced to hereditary causes. The hereditary streakings, however, are somewhat different in appearance from those of nutritional origin and can readily be distinguished by an experienced observer.

[7]Chloroses in plants may be due to many different causes, but the usual causes of the nutritional types are deficiencies of nitrogen, magnesium, iron or manganese. Nitrogen deficiencies are not likely to be confused with those of magnesium, iron or manganese, because its pattern of chlorosis is very different from those produced by deficiencies of the latter elements. Magnesium and manganese often produce their deficiency symptoms in different parts of the plant and may be further identified by pH determinations. Magnesium deficiencies are usually associated with high acidity, while manganese and iron deficiencies usually occur where the pH is 7.0 or above.

extremely small amounts of manganese and iron for normal growth. If these elements are present in more than very low concentrations, they have a harmful effect on the growth of plants. In the average soil at the medium reactions (pH 5.5 to 7.0), the supply of available manganese and iron is usually ample for crops. The supply of either is seldom too large at pH 5.5, and seldom too small at neutrality. At the extremely low pH values, however, manganese and iron are thought to be more readily available. In fact, in soils of high manganese content, manganese sometimes comes into solution in such large quantities as to be toxic to crops. The harmful effect of too much iron is thought to lie principally in its phosphate fixing activities as already discussed above. At alkaline reactions crops are sometimes deprived of the beneficial effect of manganese and iron. It has been observed that the liberal use of lime on some soils causes plants to lose their ability to develop a normal green color. Such failure has been traced to a deficiency of manganese in some cases and to a deficiency of iron in others. The deficiency of manganese is apparently one of limited supply, but in the case of iron, the trouble seems to be within the plant rather than in the soil. There is evidence that at the higher reactions plants absorb what would normally be sufficient iron, but the high lime content of the plant apparently renders the iron ineffective, causing the plant to become chlorotic.

Deficiencies of manganese and iron occur comparatively seldom. They appear on sandy soils more often than on heavier soils, and are more likely to become acute under field conditions in the spring and early summer than during late summer or fall. Furthermore, manganese deficiency troubles usually show up more frequently than iron deficiencies. The reason for this is that they generally develop at a lower pH value than iron deficiencies, and are somewhat more susceptible to other soil conditions which decrease availability. In sandy soils manganese deficiency sometimes occurs on slightly acid soils with a pH value as low as 6.5. Usually, however, soils must be limed to pH 7 (neutral) or above before manganese deficiency becomes acute.

Summarizing the Chart

After discussing the various plant foods separately, it will usually be desirable to summarize the chart in terms of farming practices. It is now apparent that intense acidity is accompanied by decreases in availability of such important plant foods as nitrogen, phosphates, calcium and magnesium.

It also favors increases in availability of aluminum, iron and manganese to the point where these elements may become injurious to crops. Here, then, are two very good reasons why high degrees of acidity should be avoided in general farming practices. On the other hand, it is also apparent that soils can be over-limed, and that the plant food situation is not as favorable above pH 7.5 as it is when the soil is neutral or slightly acid. Phosphates, potassium, manganese, and iron usually become less available when alkalinity becomes relatively intense. The chart really shows, therefore, that the extreme reactions should be avoided, and that the availability of plant foods is most favorable to crops when the soil reaction is between pH 5.5 and 7.0. For a few crops such as potatoes, strawberries, and tomatoes, it is desirable to crowd the lower limit of this range for best results. For such lime-loving crops as alfalfa and sweet clover, the soil should be limed to the upper limit of this range. A majority of the usual field and garden crops, however, do very well between pH 5.5 to 7.0, and their success at these reactions is no doubt partially due to the more favorable status of the available plant food supply. A list of suitable soil reactions for various field and garden crops is given below.

In emphasizing the importance of keeping soils in the recommended pH range, the demonstrator of the chart should guard against leaving the impression that merely adjusting the pH value to a point within the proper range will automatically furnish the plant with sufficient available foods. In many cases it will not. Under farming conditions, pH values are usually adjusted with lime, and it long ago became common knowledge that lime is not a substitute for fertilizers. Conversely, fertilizers are not a substitute for lime. Where the available plant food supply is low it is usually advisable to add fertilizers, but it is equally advisable to make sure that the soil reaction is as near the desirable range for plant food availability as the requirements of the crop will permit. A proper adjustment of the soil reaction will not only aid in keeping added fertilizer materials in an available form, but will also improve the state of availability of the native plant foods already in the soil. However, the latter influence will often be too small or too slow to meet the demands of growing crops, and it is therefore important that the distinction between the functions of lime and fertilizers be kept clearly in mind. Adjusting the soil reaction toward a favorable point tends to accomplish the same end that fertilization brings about; but where plant food deficiencies are acute, it will seldom suffice as a complete substitute.

Suitable pH ranges for Various Field and Garden Crops

FIELD CROPS

Crop	pH range	Crop	pH range
Alfalfa	6.5 to 7.5	Millet	5.5 to 7.0
Alsike clover	6.0 to 7.0	Red clover	6.0 to 7.0
Barley	5.5 to 7.0	Rye	5.5 to 7.0
Buckwheat	5.0 to 6.5	Sorghum	5.5 to 7.0
Corn	5.5 to 7.0	Soybeans	5.5 to 7.0
Cotton	5.0 to 6.0	Sweet clover	6.5 to 7.5
Cowpeas	5.5 to 7.0	Tobacco	5.0 to 5.6
Crimson clover	5.5 to 7.0	Velvet beans	5.5 to 6.5
Grasses	5.5 to 7.0	Vetch	5.5 to 6.5
Lespedeza	5.5 to 7.0	Wheat	5.5 to 7.0
Oats	5.5 to 7.0	White clover	6.0 to 7.0
Peanuts	5.5 to 6.5		

GARDEN CROPS

Crop	pH range	Crop	pH range
Asparagus	6.0 to 6.5	Onions	6.0 to 6.5
Beans (large lima)	5.5 to 6.5	Parsnips	5.5 to 6.5
Beans (small lima)	6.0 to 6.5	Peas	6.0 to 6.5
Beans (snap)	5.5 to 6.5	Peppers	5.5 to 6.5
Beets	6.0 to 6.5	Potatoes (Irish)	5.0 to 5.4
Cabbage	5.5 to 6.5	Potatoes (sweet)	5.0 to 5.5
Cantaloupe	6.0 to 6.5	Pumpkins	5.5 to 6.5
Carrot	5.5 to 6.5	Radish	5.2 to 6.5
Cauliflower	6.0 to 6.5	Rhubarb	5.0 to 6.5
Celery	6.0 to 6.5	Salsify	6.0 to 6.5
Corn (sweet)	5.2 to 6.5	Spinach	6.0 to 6.5
Cucumber	5.5 to 6.5	Squash	5.5 to 6.5
Eggplant	5.5 to 6.5	Strawberries	5.0 to 6.5
Kale	5.5 to 6.5	Tomatoes	5.5 to 6.5
Lettuce	6.0 to 6.5	Turnips	5.5 to 6.5
Mustard	5.5 to 6.5	Watermelons	5.0 to 5.5
Okra	6.0 to 6.5		

These reaction ranges are for soils which are adapted to growing the various crops listed. Thus, the pH values given for garden crops have application to the sandier soil types, because it is on such soils that commercial vegetable growing is concentrated. For the heavier types of soil and on soils which are very high in organic matter the pH range for satisfactory production of each crop would be somewhat wider. The pH values given for most of the field crops are for soils which are heavier in texture than those devoted to commercial vegetable production.

Amounts of Lime Required to Change pH Values

Different soils will require different amounts of lime to adjust the reaction to the proper range. The texture of the soil, the organic content, the prevailing reaction, the crop to be grown, the kind of lime to be used, and the soil type are factors which should be taken into consideration. Sandy soils require much less lime than heavy or fine-textured soils. Soils low in organic matter require less lime than soils high in organic matter. For practical liming recommendations the following amounts of lime per acre will be found to be satisfactory for changing the reaction of soils 1.0 pH unit when the organic matter content is average or medium. For soils low in organic matter these amounts may be reduced 25 percent, but for soils high in organic matter they should be increased 100 percent (doubled).

Soil class	Pounds required per acre to change reaction 1.0 pH		
	Burnt lime	Hydrated lime	Ground limestone, marl, or oyster shells
Light sandy	840	1,110	1,500
Sandy loams	1,120	1,480	2,000
Loams	1,680	2,220	3,000
Silt loams and clay loams	1,960	2,590	3,500

Example.—A sandy loam soil which is to be planted to corn was found to have a reaction of pH 4.5. To raise this reaction to pH 6.5 (2.0 pH units) would require 2,000 × 2, or 4,000 pounds of ground limestone per acre or its equivalent in other forms of lime.