Interpretation of . . .
SOIL TESTS

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Interpretation of Soil Tests

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A profitable response to application of fertilizer materials depends on the individual crop requirements and the soil's ability to supply the mineral nutrients essential for plant growth. Different crops have vastly different mineral requirements. Soils likewise vary widely in ability to supply essential plant nutrients.

Soil tests made by the Soil Testing Laboratory give quantitative information on the supply of five of the essential nutrients -- phosphorus, potassium, calcium, magnesium, and boron, plus the soil reaction (pH), total bases, and soil organic matter. These tests serve as a basis for fertilizer and lime recommendations. Information on the response of different crops to definite rates of fertlizer materials is needed to complete recommendations for rate and type of material to use.

Over the years, Oregon State University has conducted many different field fertilizer trials in cooperation with farmers throughout the state. Relationships between soil test values and actual crop responses from different rates of fertilization have been tested. Soil test values compared with responses from these controlled trials provide the basis for fertilizer recommendations.

The Soil Testing Laboratory reports results of analyses of a soil sample in terms of pounds per acre, parts per million, or milliequivalents per 100 grams of soil. Pounds per acre (lbs/A) refers to the amount of nutrient, in pounds, found in an acre of soil down to plow depth or about seven inches. This quantity of soil weighs approximately 2,000,000 pounds. Parts per million (ppm) refers to the amount of nutrients found in 1,000,000 parts (pounds) of soil. It can be seen that parts per million is one-half the value of pounds per acre (ppm x 2 = lbs/A). Milliequivalents (m.e.) are an expression of the chemical weights of the different nutrients. One chemical milliequivalent of any nutrient cation is equal to a chemical milliequivalent of any of the other cations. However, due to a difference in molecular weight, each element represents a different weight as follows:

1 m.e. of hydrogen	per 100 gm. of soil =	20	lbs. per acre
1 m.e. of magnesium	per 100 gm. of soil =	240	lbs. per acre
1 m.e. of calcium	per 100 gm. of soil =	400	lbs. per acre
1 m.e. of sodium	per 100 gm. of soil =	460	lbs. per acre
1 m.e. of potassium	per 100 gm. of soil =	780	lbs. per acre

These three methods of expressing nutrient levels are adapted to the different analytical methods followed in the laboratory, and permit best use of the information in developing fertilizer and lime recommendations. Though stated in different terms, all are quantitative values. Quantitative values are preferable to the comparative values (low, medium, and high) sometimes used in reporting soil-test information, because of wide variations in nutrient requirements of different crops, in climatic range, and in other factors influencing the nutrient-supplying power of Oregon soils.

It should be understood that results reported are based on the particular methods used by the OSU Soil Testing Laboratory and may not correspond with results from other laboratories where different methods or procedures are involved. However, interpretations from these laboratories, if reliable, should be comparable.

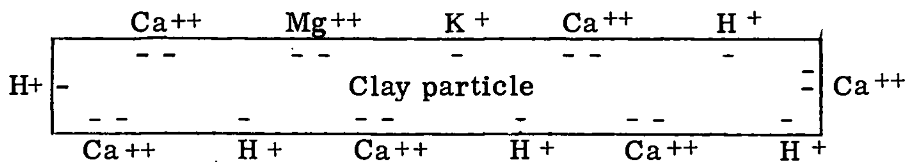
Information given here is only a general guide for interpretation of soil tests made in the Soil Testing Laboratory. It is to be used in conjunction with recommendations established for specific crops as published in the Fertilizer Recommendation series.

Soil Chemistry

Since soil tests are a means of evaluating the levels of nutrients present in a soil which are available to plants, some knowledge of soil chemistry is important in applying these tests to fertilizer recommendations.

Certain nutrient ions such as calcium, magnesium, potassium, sodium, and hydrogen have positive (+) charges and are attracted and held in the soil by clay particles and organic matter which have negative (−) charges on their surface. Sand and silt contribute very little to this phenomenon. Calcium, magnesium, potassium, and sodium contribute to a basic reaction, while hydrogen contributes to an acid reaction. In an acid soil, degree of acidity is in direct proportion to the amount of hydrogen present -- the more hydrogen the more acid the soil. Sodium is present in appreciable quantities only in the salt-affected soils of eastern Oregon.

Positively charged ions are called "cations." Calcium, magnesium, potassium, and sodium are basic cations while hydrogen is an acid cation. The capacity of a soil to hold or exchange cations is referred to as its Cation Exchange Capacity. The total Cation Exchange Capacity of a soil is expressed in milliequivalents (m. e.) of cations per 100 grams of soil. When the soil has its entire exchange capacity satisfied with basic cations, it is completely base saturated. When basic cations satisfy a part of the exchange capacity, the degree of saturation is expressed as a percentage of total capacity satisfied by such cations. For example, a soil having 15 m. e. of bases with a 20 m. e. exchange capacity is said to be 75% base saturated.



This figurative clay particle has 20 negative (-) charges. Five charges are satisfied with hydrogen. Fifteen charges are satisfied with bases (calcium, potassium, and magnesium) which make it 75% base saturated. Of these 15 charges:

12 charges are satisfied with calcium = 60% calcium saturated
2 charges are satisfied with magnesium = 10% magnesium saturated
1 charge is satisfied with potassium = 5% potassium saturated

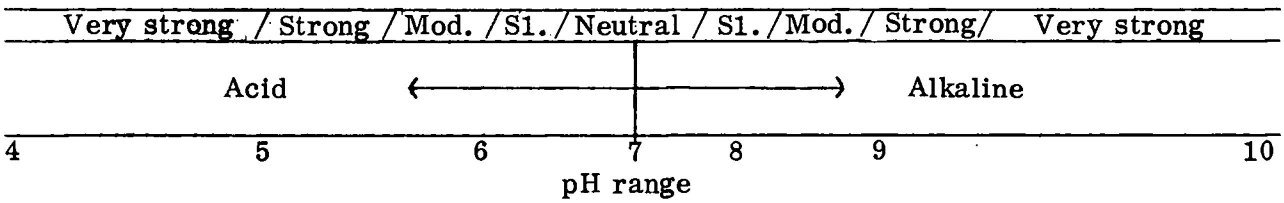
It is understandable that the Cation Exchange Capacity (CEC) of a soil will increase as the total amount of clay and organic matter increase. The type of clay also determines to a large extent the Cation Exchange Capacity of a soil. For example, one percent of the following clays will contribute to the CEC of a soil as follows:

montmorillonite	1.0 m.e./100 grams
illite	0.3 m.e./100 grams
kaolinite	0.08 m.e./100 grams
hydrous oxides.	0.03 m.e./100 grams

Each percent of organic matter may contribute from 1.5 to 2.0 m.e. to the CEC of a soil. Most soils contain a mixture of clays along with some organic matter.

Soil Reaction (pH)

Soil pH is a measure of the active hydrogen in the soil solution and indicates the degrees of acidity or alkalinity. At pH 7.0 a soil is neutral. As soil acidity increases, pH values decrease; as soils become more alkaline, pH values increase. The values which represent pH are logarithmic. For example, pH 6 represents 10 times more acidity than pH 7.0 and pH 5 is 10 times more acid than pH 6. The same is true on the alkaline side of pH 7.0. Degrees of acidity and alkalinity are shown in the following diagram for mineral soils:



When soil reaction is pH 5.5 or lower, only acid-loving plants do well. Heavy lime application may be necessary for good growth of most cultivated crops.

Soils with a pH reading of 5.5 to 6.5 are considered moderate to slightly acid. If these soils are fertile they will produce good yields of many crops. However, crops such as legumes may require lime applications for top yields.

Soils with a pH reading of 6.5 to 7.5 are practically neutral. This is the ideal soil reaction for most cultivated crops.

Soils with a pH reading of 7.5 to 8.5 are slight to moderately alkaline. Growth of many crops may be limited in this range.

Soils with a pH reading above 8.5 are considered strongly alkaline. With special attention, alkaline-tolerant plants may make fair growth. Usually reclamation measures are necessary before these soils can be used for farming.

Changes in soil pH can be brought about by a number of factors. The normal decomposition of organic material results in the formation of acids which, in humid areas, help leach out the bases, such as calcium and magnesium. Additions of acid or basic fertilizers cause fluctuation in soil pH. In arid areas where evaporation is high, salts may accumulate in soils, increasing pH. Then too, slight changes in soil pH occur throughout the year due to normal seasonal effects. A higher pH will normally occur in the winter or spring with a lower pH occurring in late summer or fall.

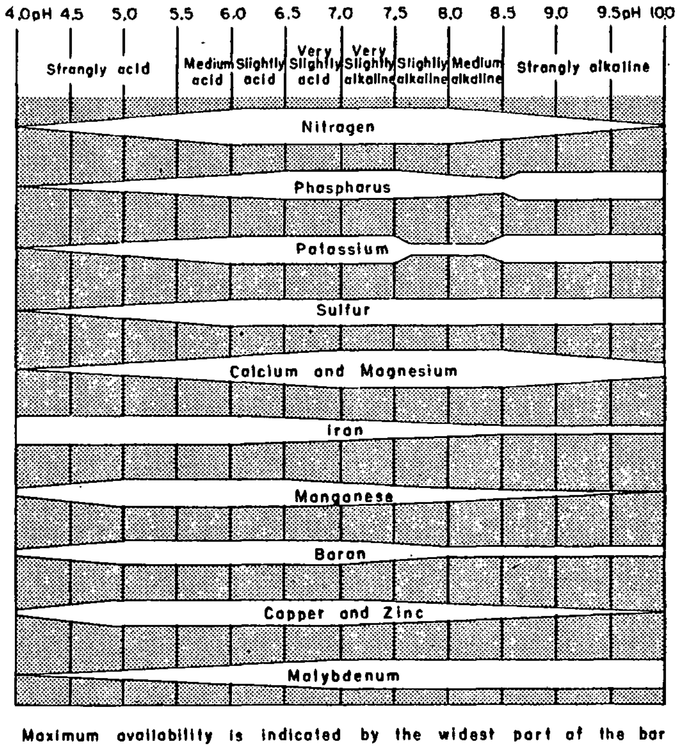


Figure 1. The influence of soil reaction (pH) on the availability of plant nutrients.

As pointed out, acid soils may be low in calcium or magnesium which are essential for plant growth. When the pH of a mineral soil is low, aluminum, iron, manganese, copper, and zinc are most soluble and may be found in quantities sufficient to become toxic to plants. As the soil pH is increased these ions become less abundant. As the soil pH increases still further to above neutrality, solubility of these ions becomes so low that deficiencies may occur.

Phosphate availability in many soils is highest when the soil is slightly acid to neutral and declines when the soil becomes strongly acid or alkaline. Boron deficiencies may occur when too much lime is added to a soil, while molybdenum is most deficient in acid soils and becomes more available as a soil is limed.

Bacteria which fix nitrogen in soils in association with the roots of legumes are most active in neutral or slightly alkaline soils.

Phosphorus (P)

The total phosphorus content of soils is extremely variable but generally low. Available soil phosphorus originates from breakdown of soil minerals, soil organic matter, or previous additions of phosphate fertilizer and is only about 0.5% to 1% of total soil phosphorus. More important, most of the total phosphorus that is applied will be tied up chemically in a form not usable by the crop during a single growing season -- it is not available to the growing plant.

Phosphorus occurs naturally in soils as calcium phosphates or apatites and as organic phosphorus with various combinations constituting as much as 75% of total soil phosphorus. Phosphorus applied as fertilizer changes into a form similar to the native forms present. One characteristic feature of soil phosphorus is its low solubility in water or the soil solution.

Changing soluble phosphates into less soluble phosphates in the soils is called fixation or reversion. The nature of the fixation may affect phosphorus fertilizer efficiency differently on different soil types. Acid soils contain a large excess of iron and aluminum, while alkaline and calcareous soils contain calcium. In either case they readily combine with water-soluble phosphates (such as super-phosphate) and convert it into sparingly soluble forms. Iron and aluminum phosphates are least soluble at pH 4 with their maximum availability occurring in the pH range of 6.5 to 7.0. As the pH increases from 7 to 8.5 in alkaline soils, the availability of phosphorus decreases due to formation of calcium phosphates.

Phosphorus is reported in pounds per acre. This is not the total amount available for crop production, but it is the amount of phosphorus removed by the particular extracting reagent used by the Soil Testing Laboratory. Crop responses in the field have been, and will be, correlated with this soil test and all fertilizer recommendations for specific crops are based upon it.

Potassium (K)

Most of our mineral soils, except those high in sands, are comparatively high in total potassium -- often containing 2 to 3% in a surface foot. Yet the quantity of potassium held in an easily exchangeable form at any one time is often small. Potassium in the soil can be listed by availability into three general groupings -- (1) unavailable, (2) slowly available, and (3) readily available.

Most of the total soil potassium is in relatively unavailable forms. These are the high potassium minerals in the soil and sand fractions constituting the micas and feldspars. The slowly available form of soil potassium is that part of the potassium which is held by the clay complex, not on the surface but within the structure of the soil clay. This potassium should not be considered as a total loss but as a reserve which will become available through normal processes. These processes consist of cropping, freezing and thawing, wetting and drying, liming, and normal tillage practices. Under certain conditions, some of these same phenomena may cause added potassium to revert to this slowly soluble form.

The readily available fraction constitutes only a small percentage of the total potassium in average mineral soil. It exists in two forms -- potassium in the soil solution and the exchangeable potassium adsorbed on the surface of soil clay. These two forms of readily available potassium are in equilibrium with each other. When the plants take up some of the water-soluble potassium from the soil solution, then more becomes available from the soil clay. When water soluble potassium is added to the soil, then some of the potassium is adsorbed onto the clay particle.

Potassium is reported both in pounds per acre and as milliequivalents per 100 grams (m.e./100 gm.) of soil. Fertilizer recommendations for specific crops are based on pound-per-acre values. The expression of potassium in milliequivalents is useful in determining total amount of bases found in the soil. (See later section.)

Calcium and Magnesium

Calcium and magnesium are essential plant nutrients. Levels of these elements are usually higher in soils of alkaline reaction than in soils with an acid reaction. Both calcium and magnesium are found in relative abundance in alkaline soils. Where acid soils are limed, the amount of calcium needed for crop production is usually met. Most liming materials contain from 0.5 to 1.5 percent magnesium, which is adequate for most crops. However, crops such as crucifers, which require a large amount of magnesium, may need an additional application, depending on the magnesium soil test value.

Total amounts of calcium and magnesium in the soil, ratio of calcium to magnesium, and ratio of magnesium to potassium are important in making fertilizer recommendations. If the amount of magnesium exceeds the amount of calcium present in the soil, there may be a problem with crop production. If calcium and magnesium are both fairly high, there is normally no problem; however, if they are both low, then the amount of calcium should be 1 1/2 to 2 times as much as magnesium. Potassium uptake may be reduced when it is very low in relation to the total amount of calcium and magnesium. So far there is limited information as to where these levels occur.

Total Bases and Lime Requirement

Liming may be necessary to improve acid soils and provide a better environment for the production of crops. This is especially true for legumes. The addition of lime may also increase the efficiency of fertilizers. A change in soil reaction due to liming may change the availability of some nutrients to plants (as noted in the section on Soil Reaction).

The lime requirement of a soil depends on the soil reaction (pH) and/or the percent base saturation best suited to the crop under consideration. Some crops grow better under more or less acid conditions than others.

Total bases, as shown in the Soil Test Report, is the summation of the milliequivalents of calcium plus magnesium plus potassium. This value, when divided by the cation exchange capacity, gives the percent base saturation of the soil. This was explained fully in the Soil Chemistry section.

Work in Oregon and elsewhere has shown that an excellent correlation exists between pH and percent base saturation for any particular soil. By taking a number of samples of any one soil series and determining pH and percent base saturation, a curve can be drawn which will be representative of practically all soils of that series. This is shown in Figure 2. However, it must be remembered that any other soil series may have an entirely different pH-percent base saturation curve. A knowledge of this relationship should make it possible to calculate the amount of lime needed to change a soil from one pH level to another or to vary the percentage of base saturation.

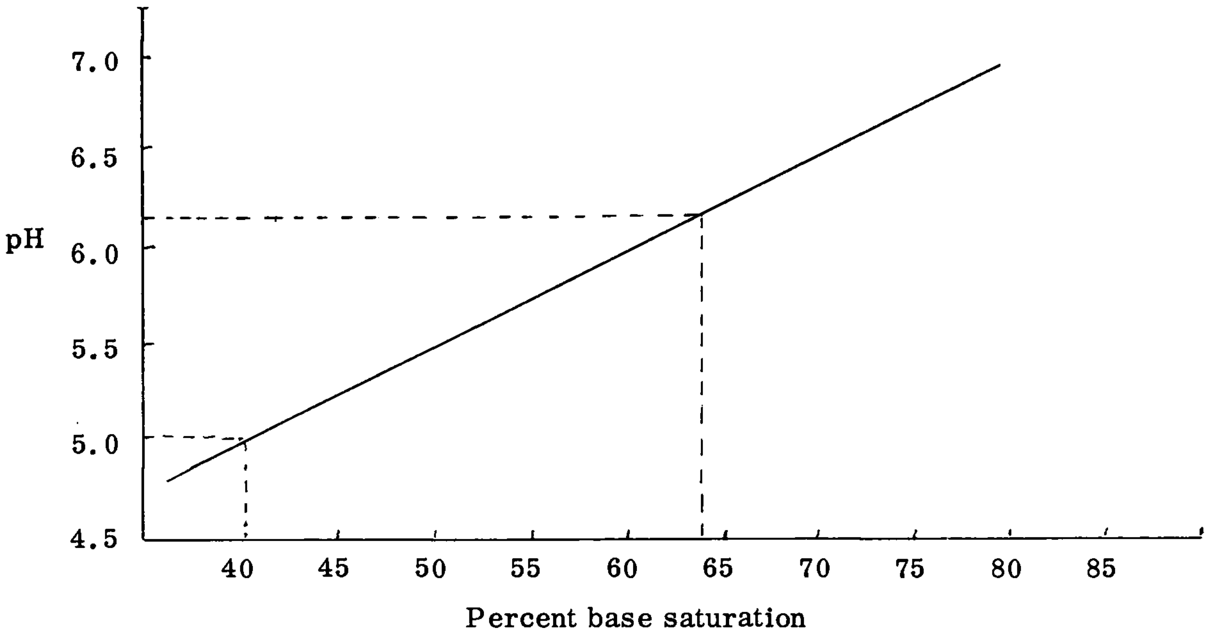


Figure 2. A typical pH-percent base saturation curve for a soil series.

An example follows: A soil sample from the soil series represented in Figure 2 has a pH of 5.0 with 10.0 m.e. of total bases. What is its lime requirement? From the curve in Figure 2, it can be seen that at pH 5.0 the percent base saturation is 40.

Assume that it is desirable to lime the soil to 80% base saturation. The increase in percent base saturation will be directly proportional to the increase in total bases for that soil. So, 80/40 x 10 = 20 m.e. of bases needed at 80% base saturation. This is an increase of 10 m.e. over the amount originally in the soil. As each ton of limestone supplies 2 m.e. of bases, 5 tons of lime will be required to supply the additional 10 m.e. of bases.

Or assume that it is desirable to lime the soil to pH 6.2. As noted from the graph, this would be at 64% base saturation. Applying the same principle, 64/40 x 10 = 16 m.e. of bases needed. Subtracting 10 m.e. and dividing by 2 indicates a requirement of 3 tons of lime to lime to pH 6.2.

It is important to remember that the above is a specific case, and that the lime requirement for any soil has to be based on the pH-percent base saturation curve for that soil series.

Nitrogen

The greater portion of nitrogen in the soil is part of the soil organic matter. In this form it cannot be utilized by the plant. Soil organic matter is decomposed by soil organisms that release nitrogen or ammonia. This change from organic to available nitrogen depends upon such factors as moisture, temperature, and soil reaction. The amount of nitrate nitrogen in the soil is transient, varying greatly within relatively short periods. In irrigated or humid regions the amount of nitrate nitrogen available at any particular time bears little relationship to responses to be expected from nitrogen fertilizers.

Recognizing the importance of nitrogen to crop production in Oregon, the Experiment Stations and Extension Service conduct field experiments in which effects of nitrogen on crop yields are studied. Present methods of testing soils for nitrogen and subsequent predictions of amounts needed, however, are either known to be inadequate or have not been correlated with crop responses to nitrogen fertilizers under Oregon conditions. Until adequate tests are available, nitrogen recommendations will be based on crop response and field experiments.

Boron

Loss of available boron through crop removal, leaching, and reversion to unavailable forms, coupled with the higher boron uptake associated with higher yields, has resulted in boron deficiency in many soils. These losses must be recognized and adequate amounts restored through the application of boron materials.

Boron contents of most Oregon soils will vary from 0.2 to 3.0 parts per million (ppm). Generally 1.0 ppm indicates a level that would be considered adequate for plant needs under most conditions. Data indicate that cereals, grasses, and corn have never shown a response to boron applications in Oregon.

Soil moisture is a main factor affecting boron availability. The highest concentration of available boron is in the surface soil. As soils dry out, plant roots are forced to feed from lower depths where boron may be deficient. This accounts, in part, for the fact that boron deficiency in dryland alfalfa may not show up until the second crop. Overliming may also reduce boron availability. This may be due to lime-induced fixation of boron by clay and other minerals.

Boron is reported as parts per million (ppm) in the soil, and recommendations are made for specific crops.

Sulfur

Sulfur is essential for plant growth. It is supplied from soil, rain, irrigation water, fertilizers, and the atmosphere. Soils located near industrial plants where rain brings down the sulfur from the atmosphere and soils irrigated with water high in sulfates are usually well supplied with sulfur for crop production. Many extensively used fertilizers also supply sulfur. Single superphosphate contains 10% sulfur while ammonium sulfate, ammonium phosphate (16-20-0), and potassium sulfate contain 24, 14, and 18% sulfur, respectively.

With increased use of sulfur-free fertilizers, such as treble superphosphate, ammonium nitrate, and aqua and anhydrous ammonia, addition of sulfur to soil is not keeping up with crop removal and leaching.

Most sulfur is in the organic form. Even sulfur added with fertilizers is soon converted to organic form by soil microorganisms. Practical ways of measuring organic sulfur or its rate of availability have not been fully developed. Sulfur recommendations will be based on crop response and field experiments.

Organic Matter

Soil organic matter is ever-changing as it passes through stages of decomposition, yet the total quantity remains fairly stable. This stability is due to constant additions of new organic materials in the form of roots, leaves, and stems of plants and bodies of dead microorganisms. Organic matter is formed from the biological decomposition of plant and animal residues. The process of decomposition converts original organic materials into carbon dioxide, water, mineral elements, and other organic compounds which are fairly resistant to further breakdown.

When decomposition is slow, partially decomposed organic matter may accumulate in the soil. This is true for several coastal soils where cool weather prevents maximum microbial activity. In eastern Oregon where temperatures are higher and microbial activity is also high, decomposition proceeds more rapidly than renewal, so the total amount of organic matter is low.

As the amount of organic matter in the soil changes slowly, there is little reason to make this determination on any field more often than once every 6 to 10 years. Even though many crops can be and are grown on soils low in organic matter, in some areas soil productivity can be increased by increasing the amount of organic matter.

Salt-Affected Soils

Salt-affected soils are widespread in the arid and semiarid areas of the west. The degree to which soils are affected varies from a low level that allows most crops to grow well to levels so high that no crops at all can be grown. Soil tests give a good indication of the type and extent of the problem involved -- as discussed in the next two sections.

By definition, "salt-affected soils" are those soils that have been adversely modified for the growth of most crops by the presence or action of soluble salts. The term includes soils having an excess of soluble salts, or an excess of exchangeable sodium, or both.

Salinity

The main effect of soil salinity on crops is to make it difficult for roots to take up water. As the soil solution becomes more concentrated with salt, the roots are less able to adsorb water into their system. In other words, water is less readily available as the soil becomes saltier. A given amount of salt is more injurious to a sandy soil than to a clay loam soil, because a sandy soil holds less water and, therefore, produces a saltier solution.

In testing for soil salinity where crops are involved it is usually not necessary to analyze for the separate salt constituents. A measure of total salinity is generally sufficient. An extract of the water-saturated soil is made, and its ability to carry an electrical current is measured. As an increase in salt increases the electrical conductance through a water solution, so a measure of the electrical conductivity of a soil solution provides a good index of soil salinity for agricultural purposes.

Electrical conductivity is expressed in millimhos. It is a measure of salt concentrations, and can be readily and precisely determined. This measurement of soil salinity is related to the availability of water in the soil under field conditions. Crop response at different salinity levels is indicated below.

Salinity level	Conductivity	Crop response
	Millimhos	
Very low	0 to 2	Salinity effect mostly negligible.
Low	2 to 4	Yields of very sensitive crops may be restricted.
Medium	4 to 8	Yields of many crops restricted.
High	8 to 16	Only tolerant crops yield satisfactorily.
Very high	Above 16	Only very tolerant crops yield satisfactorily.

Salinity tolerance of many species and varieties of crop plants has been investigated at the U. S. Salinity Laboratory, and they are listed in the following table. The list includes field, forage, vegetable, and fruit crops, and it is divided into tolerant, moderately tolerant, and low tolerance groups. Within each group crops are ranked in order of decreasing salt tolerance, although a difference of two or three places in the ranking may not be of any significance. The salt tolerance in millimhos is at the top and bottom of each column.

Tolerant	Moderately tolerant	Low tolerance
12 millimhos	8 millimhos	4 millimhos
Saltgrass	Flax	Carrot
Garden beets	Sweetclover	Onion
Sugar beets	Most grasses	Peas
Rhodes grass	Huban clover	Squash
Bermuda grass	Alfalfa	Cucumber
Wheatgrass	Big trefoil	Radish
Fescue grass	Sunflower	Celery
Kale and rape	Field corn	Green beans
Tomato	Wheat & oats (hay)	Wheat & oats (grain)
Barley (hay)	Cole crops	Meadow foxtail
Asparagus	Lettuce	Most clovers
Spinach	Sweet corn	Field beans
Ryegrass	Melons	Strawberry
Birdsfoot trefoil	Potatoes	Apple & pears
Barley (grain)	Bell peppers	Stone fruits
8 millimhos	4 millimhos	2 millimhos

Sodium effect

Sodium may accumulate in the soil for a number of reasons. It may be added by irrigation water high in sodium; it may be left behind from a salty (saline) soil when pure irrigation water dissolves and leaches out other salts; or it may rise to the surface soil from lower depths when water rises and evaporates from the surface. Many sodium (sodic) soils are formed after the soil is put under irrigation. Others have been formed for centuries. Localized areas of sodic soils are often called "slick spots."

For each soil a close relationship exists between sodium and the calcium-magnesium content of the soil solution and the relative proportion of these cations present in an exchangeable form in the soil. This relationship is sufficiently similar for most soils to make it a useful tool in estimating the exchangeable sodium status of a given soil.

The soil test for sodium involves a determination of the concentration and combination of salts present. The result of this test is referred to as the "sodium effect." If the proportion of sodium to calcium and magnesium is high, the sodium effect on crops will be high; and conversely, if calcium and magnesium predominate, the sodium effect will be low.

Soils are divided into four classes depending on the intensity of the sodium problem. Laboratory results are reported as follows:

No effect - - - - - -	No effect on plant growth.
Low - - - - - - - -	Little harmful effect to soils or plant growth except for sodium-sensitive crops.
Medium - - - - - -	May be detrimental to soils having poor drainage.
High - - - - - - - -	Growth of most crops restricted. Additions of amendments and leaching may be necessary for normal crop production.

If a sodium problem exists, the following general crop tolerances may be useful:

Extremely sensitive - - -	Deciduous fruits, nuts, citrus.
Sensitive - - - - - - - - - -	Beans.
Moderately tolerant - - -	Clovers, oats, most grasses.
Tolerant - - - - - - - - - -	Alfalfa, wheat, barley, cotton, sugar beets, tomatoes.
Most tolerant - - - - - -	Wheatgrasses.

Whenever salinity or exchangeable sodium content exceeds limits established for normal crop production, reclamation and special management practices are essential. Excess salinity of the soil solution can usually be corrected by leaching with water of good quality; however, removal of excess exchangeable sodium also requires the application of an amendment such as gypsum. In either case adequate drainage is important and must be provided.

If a preliminary soil test shows the presence of a saline or sodium condition, further sampling of the field may be necessary to determine the boundaries of the problem area.