24959-89

Soil and Irrigation Water Interpretation Manual

Printed in U.S.A.

5-15-93-2ED, rb rev1 10/01

TABLE OF CONTENTS

Page

PREFACE

SECTION I

SECTION II

PREFACE

This manual will acquaint the user of the NPK-1 and SIW-1 Test Kits with basic concepts related to soil, soil fertility, plant nutrition, and irrigation water quality. A glossary is included to help the user understand unfamiliar terms used in this manual and the NPK-1 and SIW-1 Procedure Manuals.

This manual provides the necessary information to help the analyst evaluate test results. It also contains fertilizer recommendations to help determine the proper amount of fertilizer in relation to soil test values, crop, and yield goal. Although these recommendations are in the public domain, they are only recommendations. Hach Company assumes no responsibility to the applicability or accuracy of these recommendations. They are included only as a resource for the analyst.

The fertilizer recommendations and information related to soil testing were provided by Dr. Raymond Ward of Ward Laboratories in Kearney, Nebraska. Dr. Ward compiled this information from extension service bulletins published by Oklahoma State University, Kansas State University, and Nebraska State University.

The information on irrigation water quality was compiled from extension service information from Colorado State University and from papers by Dr. Jim Rhoades (Director of the United States Salinity Laboratory in Riverside, California). More information about irrigation water and/or salt affected soils is available from the United States Salinity Laboratory and the land grant universities of the Western United States. Outside the United States, this information may be obtained from the local ministry of agriculture or universities.

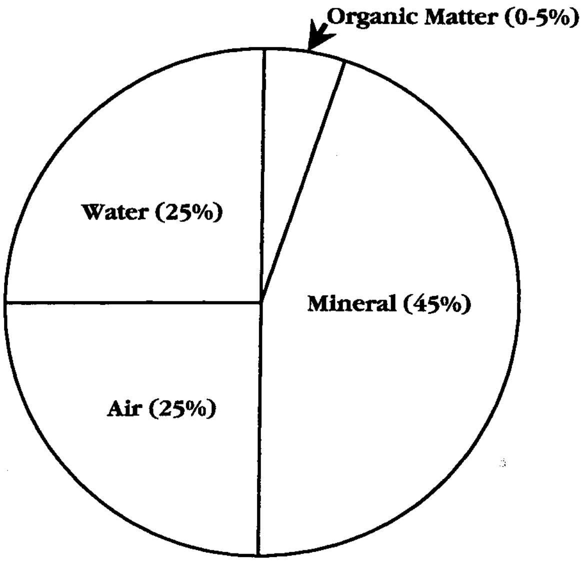
More specific, in-depth information about soil and soil fertility, is found in libraries, especially those of colleges that teach the agricultural sciences.

SECTION I

AN INTRODUCTION TO SOIL

Soil is a complex natural material made of disintegrated rocks and decayed organic material which provides nutrients, moisture, and support for land plants. Soil is a three-phase system of solid (minerals and organic materials), liquid (water), and gas (air) as shown below.

Phases of Soil



PHYSICAL PROPERTIES OF SOIL

Soils are usually characterized by their **physical** and **chemical** properties. These properties determine how productive the soil will be.

Texture: The relative proportions of sand, silt, and clay. Sand, silt and clay are known as the soil separates.

Structure: The aggregation of soil particles into definite forms that are characteristic of a soil's history and composition.

Density: How compact the soil is; the mass of a soil divided by its volume.

Porosity: The amount and size of space between soil particles; related to soil compactness and the bulk density of the soil.

Consistency: The ability of soil particles to stick together. This is related to the amount and type of clay in the soil and is a measure of the soil's behavior under mechanical stress.

Color: A measure of value, chroma, and hue. It indicates a soil's composition and history. Soil color is determined using the Munsell Color Chart (available through agricultural supply companies).

Temperature: Degree of hotness or coldness which contributes to the success of microbial and chemical activity and seed germination.

CHEMICAL PROPERTIES OF SOIL

Cation Exchange

The USDA Soils Laboratory defines cation exchange as the interchange of a cation (positive ion) in the soil solution with another cation on the surface of colloidal clay or humus. Essential nutrient cations in the soil colloids include calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+), and non-essential nutrient cations like hydrogen (H^+), aluminum (Al^{3+}), and sodium (Na^+).

These ions maintain ionic equilibrium with cations in the soil solution. The cationic exchange at the soil-water interface is regulated by the type and quantity of ions present. Cations on the soil colloids are referred to as "exchangeable" because they can be available for plant growth. Although more dilute than those contained on the soil colloids, nutrients in solution are directly available for plant use.

A simple cation exchange reaction is illustrated below in a soil with high levels of adsorbed calcium and optimum temperature and moisture conditions:

$$\text{[colloid]Ca} + 2\ H^+ \begin{array}{c}\rightarrow H\\ \leftarrow H\end{array} \ \text{[colloid]} + Ca^{2+}$$

The hydrogen ions are supplied by organic decay that results in mineral and organic acids. The H+ ions replace the Ca^{2+} ions on the colloid because there are more of them and they are held more strongly than calcium ions by the colloid.

If the soil became less acid (less H^+) or limestone was added to the soil (increases Ca^{2+}), the reaction would occur in the opposite direction. On the other hand, if the soil became more acid or calcium was removed by leaching or crop use, the reaction would proceed to the right at a faster rate.

In real conditions, the colloid has many cations on its surface. When there is enough rain to remove calcium from the soil, the reaction will proceed to the right. In low rainfall climates, the reaction occurs less often, which keeps the soil at a pH 7 or more.

Cation Exchange Capacity (CEC)

Cation exchange capacity refers to the total number of cations a soil can adsorb through cation exchange. CEC is usually expressed as milliequivalents (meq) of cations per 100 grams of soil.

Sandy (coarse) soils usually have a low CEC. As the soil texture becomes more fine, CEC values generally increase. Soils also increase in CEC with an increase in organic matter content (humus).

CEC values are also affected by the type and amount of clay present. The young, expandable clays such as montmorillonite and vermiculite generally have higher CEC values than older nonexpanding clays like the kaolinites and illites.

Percent Base Saturation (%BS)

Colloids have two groups of cations that have opposite effects on soil acidity. One group contributes hydrogen ions to the soil solution (H^+, Al^{3+}). The other group, called exchangeable bases (Ca^{2+}, Mg^{2+}, Na^+, and K^+), neutralize soil acidity. The part of the cation exchange capacity occupied by these neutralizing bases is called the percent base saturation. Percent base saturation is described by the following equation:

%BS = total number exchangeable basic cations ÷ CEC

For example, if a soil's CEC is 20 milliequivalents/100 grams and the total number of exchangeable basic cations is 18 meq/100 grams, then the %BS would equal (18÷20) X 100 or 90%.

Generally the soil pH increases as the %BS increases. Humid soils that become acidic due to calcium removal can have a %BS of less than 66%. Soils with a low %BS are acidic and high in exchangeable H^+ and Al^{3+} content. These soils require lime to increase the %BS and pH to levels that are optimal for crop production. Soils in more arid regions have a pH near 7 and percentage base saturations of almost 100%.

Soil Reaction (pH)

Soil pH is a measure of the soil's acidity, neutrality, or alkalinity. It is one of the best diagnostic measurements available to identify soil conditions. As shown in the illustration "Soil pH and its Affects on Nutrient Availability" (page 14), soil pH has the greatest economic benefit when all essential nutrients are available. See Soil pH for more information.

SOIL CHARACTERIZATION BY ANALYSIS

Analyzing a soil's chemical and physical properties provides information about the soil and the problems with that soil. Soil analysis also determines amounts of available nutrients (fertility level) present during the time of sampling. Therefore, soil analysis serves two important purposes:

1) diagnostic determination

2) fertility assessment.

Diagnostic Testing

Diagnostic testing isolates specific problems such as pH, salt, or texture which can decrease fertility and/or productivity. Once these problems are identified, corrective practices can be recommended to aid profitable production.

Fertility Assessment

Fertility assessment analyzes the soil for the presence and balance of essential crop nutrients. Based on these analyses, crop production potential, past history, and research from land grant universities, fertilizer recommendations are made.

The diagnostic methods characterize the soil in one or more of the following soil classifications:

1) Acid Soils—Acid soils have a pH well below 7.0 (pH <6.0). These soils lose productivity due to low nutrient availability and presence of toxic ions such as aluminum.

2) Alkaline Soils—Alkaline soils have a pH above 7.5. These soils can be subclassed as calcareous or salt affected.

3) Calcareous Soils—Calcareous soils contain high amounts of free lime ($CaCO_3$). The pH of these soils is usually between 7.5 and 8.5.

4) Salt-Affected Soils—Salt-affected soils contain high concentrations of soluble salts (saline) and/or exchangeable sodium (sodic).

5) Sandy Soils—Sandy soils fall into the textural class of sands or loamy sand. These soils are subject to wind erosion, low fertility, or droughtiness.

6) Clay Soils—Clay soils are fine textured and present problems of drainage, wetness, and aeration.

The fertility measurements evaluate the soil's cation exchange capacity, pH, and release of soluble nutrients from organic matter and minerals. These measurements are important for determining the following:

1) A soil's ability to hold certain fertilizer elements

2) The nutrient balance in the soil

3) The percent organic matter

4) The ability to supply adequate amounts of native nutrients.

A DISCUSSION OF PROBLEM SOILS

Calcareous soils

Lime as $CaCO_3$ and/or $MgCO_3$ is present in the parent material of most soils. In humid regions, lime is usually present in low concentrations, but may be entirely absent in the topsoil due to leaching as water percolates through the soil. In arid and semi-arid regions, little leaching occurs. In this case, lime is redistributed throughout the soil profile, but is not redissolved during low rainfall. Sharply defined lime zones may result from limited rain or irrigation water which penetrates to the same depth each year. When the lime dissolves, it is redistributed by water. When the water evaporates, the lime is precipitated.

Soils high in lime generally have a pH ranging from 7.5 to 8.4. The high alkalinity affects the solubility or availability of certain nutrients. For example, available phosphorus (monohydrogen orthophosphate, HPO_4^{2-}) forms a calcium salt which precipitates into a less available form at a pH greater than 7.5, reducing the efficiency of applied phosphorus fertilizers. The availability of metal micronutrients (iron, zinc, copper and manganese) and boron is also decreased by the alkaline pH.

Calcareous soils may or may not be associated with salt-affected soils. Due to the low solubility of $CaCO_3$, some soils are 30% lime and yet are not saline. Because calcareous soils will visibly effervesce (fizz) when exposed to 2.5 N hydrochloric acid, they are easily identified.

Salt-Affected Soils

These soils contain excess amounts of either soluble salts or exchangeable sodium or both.

Saline Soils

Although salinity does not affect the physical properties of soil, it is harmful because osmotic pressure can create an artificial drought. This occurs because increased salt in the soil solution reduces the availability of soil water to plants. In extreme cases, water can actually be drawn out of the plant due to osmotic pressure, resulting in dehydration and death. Saline soils are often called white alkali due to the white salt encrustations on the soil surface.

Sodic Soils

Sodic soils are soils in which the exchangeable sodium percentage is high enough to cause a change in soil flocculation. In extreme cases, sodium ions disperse the mineral colloids, which then form a tight soil structure. This structure slows the infiltration/percolation of water. The pH of the soil due to sodium-water hydrolysis can increase to greater than 8.5, which results in dissolution of organic matter in the soil. The dispersed humus is carried upward by capillary action, making the soil black. This type of soil is often referred to as black alkali, gumbo, or slick spots. Sodic soils frequently occur in semi-arid and arid regions in small irregular areas.

Saline/Sodic Soils

These salt-affected soils contain large amounts of soluble salts and a high percentage of exchangeable sodium. They are similar to saline soils in appearance and character except that the soluble salts are leached out by artificial drainage. After leaching the soluble salts, the soils become sodic and degrade in quality.

Saline soils do not respond to chemical amendments. Only leaching the salts through adequate drainage reclaims these soils. Saline/sodic and sodic soils do respond to calcium amendments and drainage. In the case of sodium-affected soils that contain high amounts of free lime, sulfur can be added as an amendment to reclaim the soil.

Chemical Criteria for Calcareous and Salt-Affected Soils

Soil Type	pH	ECe mS/cm*	SAR**
Calcareous	7.5-8.4	< 2.0	< 13%
Saline	< 8.5	> 2.0	< 13%
Sodic	> 8.5	< 2.0	> 13%
Saline/Sodic	< 8.5	> 2.0	> 13%

*The current standard unit of conductivity is milliSiemens which is equivalent to mmhos.
**SAR is the acronym for sodium adsorption ratio which predicts the degree of sodium accumulation on the soil colloids.

The above criteria assume that conductivity and SAR measurements are made on saturated paste extracts (EC_e). However, since it is very time consuming to obtain a saturated paste extract, a method for measuring conductivity in a 1:1 soil/water suspension has been recommended by the North Central Region - 13 Soil Testing Committee of the United States. The table below shows the relationship between conductivity and degree of salinity for the 1:1 method based on four broad categories of soil texture.

Degree of Salinity
(1:1 Soil/Water Suspension)

Texture	Non Saline	Slightly Saline	Moderately Saline (EC 1:1)	Strongly Saline (mS/cm)	Very Strongly Saline
Coarse sand to sandy loam	0-1.1	1.2-2.4	2.5-4.4	4.5-8.9	9.0 +
Loamy fine sand to loam	0-1.2	1.3-2.4	2.5-4.7	4.8-9.4	9.5 +
Silt loam to clay loam	0-1.3	1.4-2.5	2.6-5.0	5.1-10.0	10.1 +
Silty clay loam to clay	0-1.4	1.5-2.8	2.9-5.7	5.8-11.4	11.5 +

Acid Soils

Acidic soils are usually found in humid regions and result from high rainfall (leaches lime and other metallic bases) and crop production. Crop production acidifies the soil in two ways. During plant growth, roots give off hydrogen ions which are acidic and must be neutralized by the soil lime. Second, most fertilizers (especially those containing ammonium nitrogen) are acidic in their soil reaction. For every pound (kilogram) of ammonic nitrogen that is applied to the soil, 1.8-2.0 lbs (1.8-2.0 kg) of lime are dissolved and neutralized.

For soils that have little lime, acid can quickly overcome the buffering capacity of the lime. These soils become increasingly acidic and eventually release soluble aluminum, which results in further acidification and toxicity. Crop growth is reduced and lime must be applied to bring the soil back to profitable production. The soil analysis called “buffer pH” or “SMP buffer” predicts the amount of lime needed to bring the soil to a normal pH.

Soils With Problem Textures

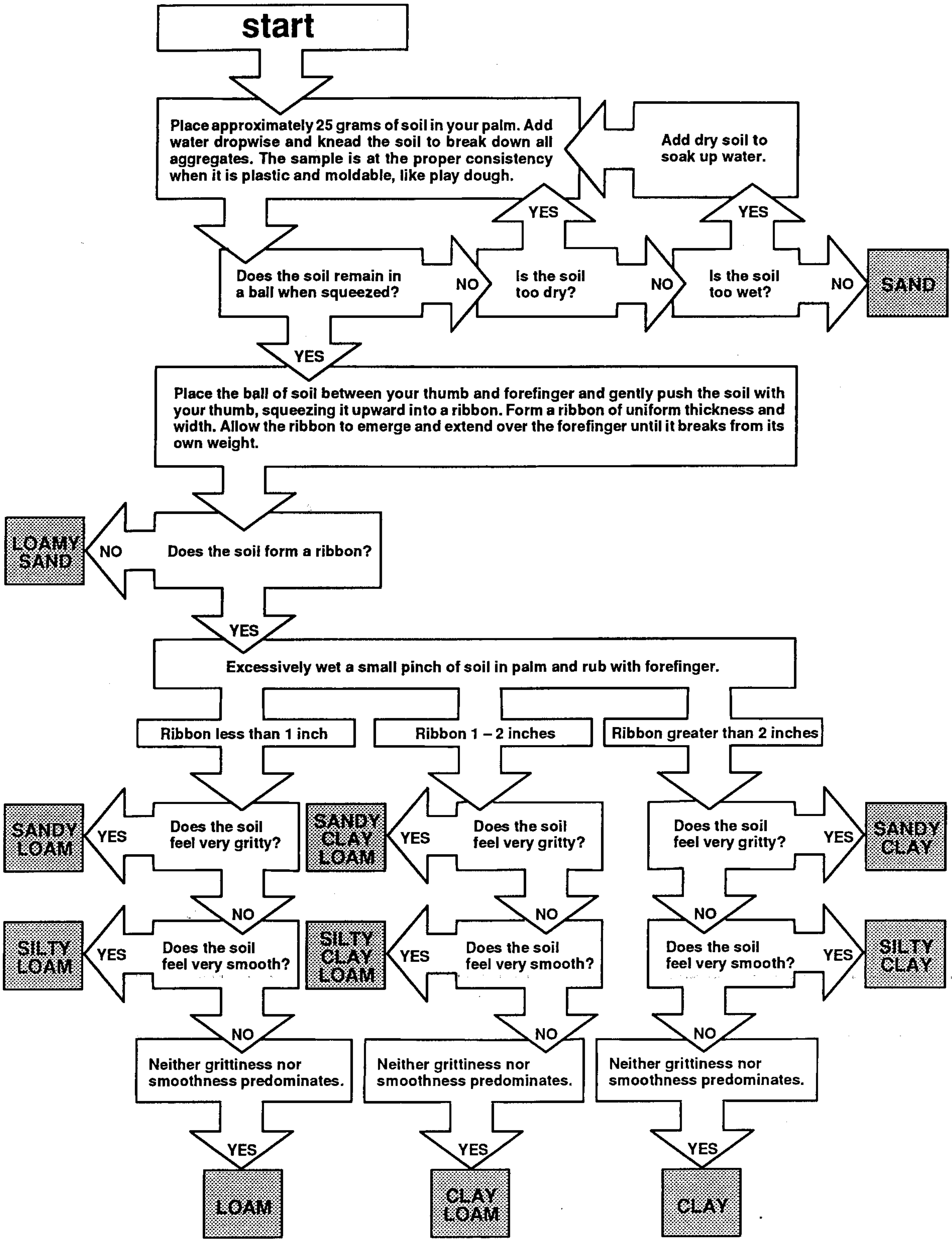
Soils are made of particles that vary in size and shape. Scientists have grouped the particles by size, and refer to the groups as “separates.” Soil separates range from very small clay particles to large sand particles. A loam soil is made of sand, clay, and silt particles. To estimate soil texture, the “feel” method is often used. See page 5 for this procedure.

Since soil separates vary so much in chemical make-up and crystal structure, they also vary in mineral and nutrient content. In addition, management of soil is influenced by soil type. The following table illustrates several management problems associated with soils of various textures.

Management Problems with Various Soil Textures

	Coarse (Sandy)	Medium (Loamy)	Fine (Clayey)
Erosion Management			
Water	Low	High	Low-Medium
Wind	High	Low	Moderate
Water Management			
Water Holding Capacity	Low	Medium	High
Infiltration	Rapid	Medium-slow	Rapid when dry Slow when wet
Percolation	Excessive	Good	Fair-Poor
Tillage Management			
Horsepower Requirement	Low	Medium	High
Tillability	Easy	Medium	Difficult
Fertility Management			
Potential Nutrient Imbalance	High	Moderate-Low	Low
Chemical Recommendations	Low	Medium	High
Aeration	Good	Moderate	Poor

Estimating Soil Texture



PLANT NUTRITION OVERVIEW

Plant nutrition is the biochemical process of absorption, assimilation and utilization of nutrients essential for growth and reproduction. Balanced plant nutrition contributes to high crop yields at the most economical return of crop investment costs (fixed or variable).

Three major factors contribute to plant nutrition:

1) The amount of nutrient in the soil. A crop may be deficient due to low amounts of nutrients in the soil. Fertilizer may be required to increase the nutrient level.

2) The soil's ability to supply the nutrients to the plants. Soil pH is very important in determining how available a nutrient is. For example, when the soil pH is above 7, many of the micronutrients (i.e., iron, cobalt, zinc) become unavailable to plants because they form insoluble salts. However, at pH 6, they are soluble enough to be available for crops.

3) Environmental factors that affect nutrient availability and absorption. Environmental conditions, such as cool and/or wet weather can intensify nutrition problems. An example is growing sorghum in Oklahoma, USA. Some Oklahoma soils have high iron content (red oxidized soils), but iron deficiency is a major problem for the sorghum crop because of high soil pH (calcareous condition) and cool, wet weather. No one knows why this combination of climate and soil conditions produces an iron deficiency.

ESSENTIAL NUTRIENTS IN PLANT NUTRITION

Sixteen elements are normally considered essential for plant growth. A nutrient is essential if a plant dies when it is absent. The essential nutrients are classified into four groups:

1) Major Non-Mineral Macronutrients
These are 90-95% of dry plant weight, and are supplied to the plant by water absorption and photosynthesis.

Carbon- C
Hydrogen- H
Oxygen- O

2) Primary Macronutrients
These nutrients are absorbed and used by plants in large amounts and are most likely to cause nutritional deficiencies for plant growth.

Nitrogen- N
Phosphorus- P
Potassium- K

3) Secondary Macronutrients
These are absorbed and used in large amounts, but are less likely to cause nutritional deficiencies in plants.

Calcium- Ca
Magnesium- Mg
Sulfur- S

4) Micronutrients
Although no less essential, plants need only trace amounts of these nutrients.

Boron- B
Chlorine- Cl
Copper- Cu
Iron- Fe
Manganese- Mn
Molybdenum- Mo
Zinc- Zn

SOIL NITROGEN

Of the 16 essential nutrients, nitrogen is the nutrient most likely to be deficient worldwide. Nitrogen is used extensively in plant growth and must be present in the plant for cell division. Nitrogen is also vital to protein production in a biological system. Without nitrogen, cell division and protein synthesis stops and the plant eventually dies. Adequate nitrogen increases water use efficiency and absorption of other nutrients by the plant.

Many soils are deficient in nitrogen. To compensate for lack of nitrogen, many soils are over-fertilized. Ironically, over-fertilization often causes a decrease in profit, rather than an increase. Although plants require a certain amount of nitrogen, any nitrogen applied and not used by the crop is wasted. This excess nitrogen can contaminate groundwater supplies, currently a major environmental concern.

Nitrogen is used by plants in two forms, ammonium (NH_4^+) and nitrate (NO_3^-). Ammonium ions are present in soils through decomposition of organic tissue or manure application. Nitrate is the final form of nitrogen decomposition, but can also be supplied by fertilizers, irrigation and precipitation *(See Nitrogen Transformation in the Soil illustration).* Other sources are also shown in this illustration.

Available nitrogen is lost from soil in several ways:

a) Volatilization—Nitrogen fertilizer not properly tilled into the soil is lost in gaseous form to the air. This is especially true for alkaline soils during hot weather.

b) Anaerobic denitrification—When a soil is flooded, oxygen is absent (anaerobic) and nitrogen is converted to nitrogen gas (N_2) by anaerobic soil bacteria. The gas is then lost to the air.

c) Leaching—Excluding crop production, this is the most significant way to lose nitrogen from soil. Leaching occurs in areas of heavy rainfall or where irrigation is used.

Normally, ammonium (NH_4^+) does not leach from soil because the positive charge is attracted and "held" by the negative charge on the surface of clay and humus particles. However, when NH_4^+ is transformed to NO_3^-, the (+) charge is lost and the soil no longer attracts the available nitrogen. Water percolating through a soil profile leaches and depletes the mobile nitrate from the upper layers to the lower layers and even into the groundwater if leaching is excessive. *Excessive nitrate leaching is most likely in fields where overfertilization has occurred.*

Nitrate in groundwater is a major environmental and public health concern. High nitrate levels in drinking water (>10 parts per million) are linked with health problems (i.e., methemoglobinemia) resulting in miscarriage or "blue babies".

Calculating Nitrogen Fertilizer Application

Before applying nitrogen fertilizer, consider a realistic yield goal and calculate the nitrogen requirement for the crop based on this goal. Subtract the following from the nitrogen requirement:

- residual nitrate in soil
- nitrate from irrigation
- nitrate from decay of organic matter
- nitrate released from animal and/or green manure

Example (U. S.)

A farmer expects a yield of corn to be 170 bushels per acre. The extension agent says it takes 2 lbs of N to produce 1 bushel of corn. So, the nitrogen requirement is 2.0 x 170 = 340 lbs of N/hectare.

Previously, the farmer applied 10 tons/acre of beef manure, which has about 14 lbs of nitrogen/ton. From the manure, 50% of the nitrogen is available during the first year after application. Testing shows the soil organic level* is 1.8%. At a depth of 24 inches**, nitrate-nitrogen measures 15 ppm (parts per million). Irrigation water† analysis shows nitrate-nitrogen levels at 6 ppm. The farmer usually uses 18 inches (1.5 acre feet) of irrigation water per hectare of land in a growing season.

*Organic Matter Nitrogen- % soil organic matter x 22 = approximate N mineralized/year (varies with location and soil texture)
**Residual Soil Nitrate- ppm nitrate in soil x 0.3 x inches of sample depth = lbs/acre of available nitrate (0.3 is based on a soil bulk density of 1.2 g/cm^3).
†Irrigation Water Nitrogen- ppm nitrate in irrigation water = lbs N applied/acre ft of water irrigated.

Example Calculation

Residual Nitrate = 15 ppm x 24 inches x 0.3 = 108 lbs N
Irrigation Water Nitrogen = 6 ppm x 2.7 x 1.5 = 24.3 lbs N
Organic Matter Nitrogen = 1.8% x 20 = 36 lbs N
Manure Nitrogen = 10 tons x 14 lbs/acre x 50% = 70 lbs
Nitrogen Requirement = 170 bushes/acre x 2.0 = 340 lbs/acre

Therefore:
340 (required) - (108 + 24 + 36 + 70) = 110 lbs/acre additional N required

Applying more than the recommended 110 lbs/acre would show little or no return on money, invested into fertilizer and greatly increases the probability of nitrogen loss due to leaching.

Example (metric)

A farmer expects a yield of corn to be 150 hectaliters per hectare. A local soils laboratory has determined that it takes 2.6 kg of N to produce 1 hectaliter of corn. So, the nitrogen requirement is 2.6 x 150 = 390 kg of N/hectare.

Previously, the farmer applied 22 metric tons/hectare of beef manure, which has about 7 kg of nitrogen/metric ton. From the manure, 50% of the nitrogen is available during the first year after application. Testing shows the soil organic level* is 1.8%. At a depth of 60 cm**, nitrate-nitrogen measures 15 ppm (parts per million). Irrigation water analysis shows nitrate-nitrogen levels at 6 ppm (6 kg N/1000 m^3 of water irrigated). The farmer usually uses 4569 m^3 of irrigation water per hectare of land in a growing season (1 hectare covered by 46 cm of water).

*Organic Matter Nitrogen- % soil organic matter x 22 = approximate N mineralized/year (varies with location and soil texture)
**Residual Soil Nitrate- ppm nitrate in soil x 0.13.3 x cm of sample depth = kg/ha of available nitrate (0.133 is based on a soil bulk density of 1.2 g/cm^3).

Example Calculation
Residual Nitrate = 15 ppm x 60 cm x 0.133 = 120 kg N/ha
Irrigation Water Nitrogen = 6 kg/1000 m^3 x 4569 m^3/ha = 27 kg N/ha
Organic Matter Nitrogen = 1.8% x 22 = 40 kg N/ha
Manure Nitrogen = 22 metric tons/ha x 7 kg N/metric ton x 50% = 77 kg N/ha
Nitrogen Requirement = 150 hl/ha x 2.6 kg N/hl = 390 kg/ha

Therefore:
390 (required) - (120 + 27 + 40 + 77) = 126 kg/ha additional N required

Applying more than the recommended 126 kg/ha would show little or no return on money, invested into fertilizer and greatly increases the probability of nitrogen loss due to leaching.

THE NITROGEN CYCLE

As organisms decompose organic material, they take the energy from them and leave simpler compounds (See Nitrogen Transformations). One of the compounds remaining is NH_3, ammonia gas. The gas is very soluble in water, and in the soil solution it reacts with hydrogen to form ammonium ions (NH_4^+). Plants absorb ammonium ions and use it to make new living matter. This is the short path in the nitrogen cycle (*See Nitrogen Cycle drawing).*

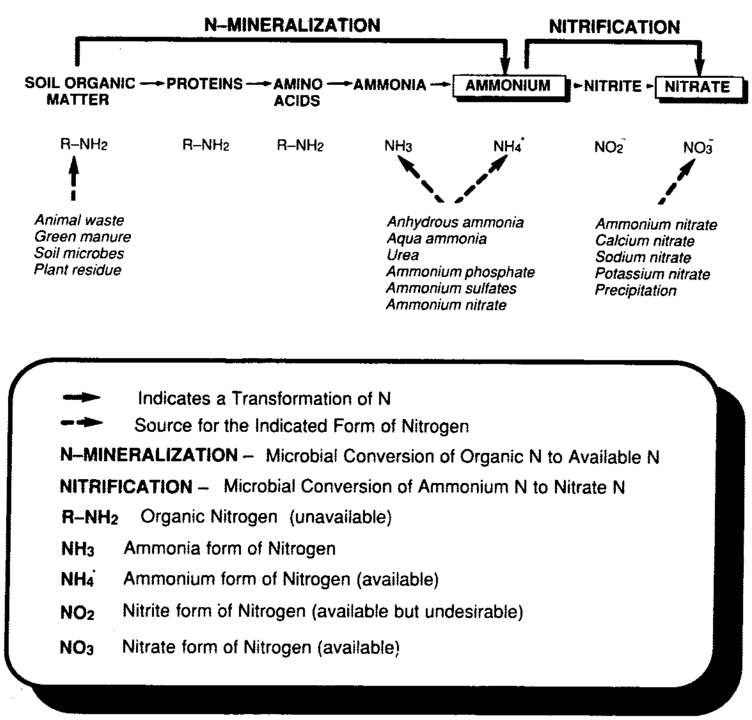
Two groups of nitrifying bacteria change complex nitrogen into simpler nitrogen forms. One group changes ammonium ions (NH_4^+) to nitrite ions (NO_2^-). The other group transforms nitrite ions to nitrate ions (NO_3^-). Plants use nitrate ions as their main source of nitrogen. This is the second pathway in the nitrogen cycle.

These nitrifying bacteria can only transform nitrogen compounds to simpler compounds if oxygen is present (aerobic conditions). If oxygen is not present, denitrifying bacteria change nitrates to nitrogen gas. Most of the gas escapes to the atmosphere and is not available for plants, but some of the nitrogen gas is returned to the soil through two paths:

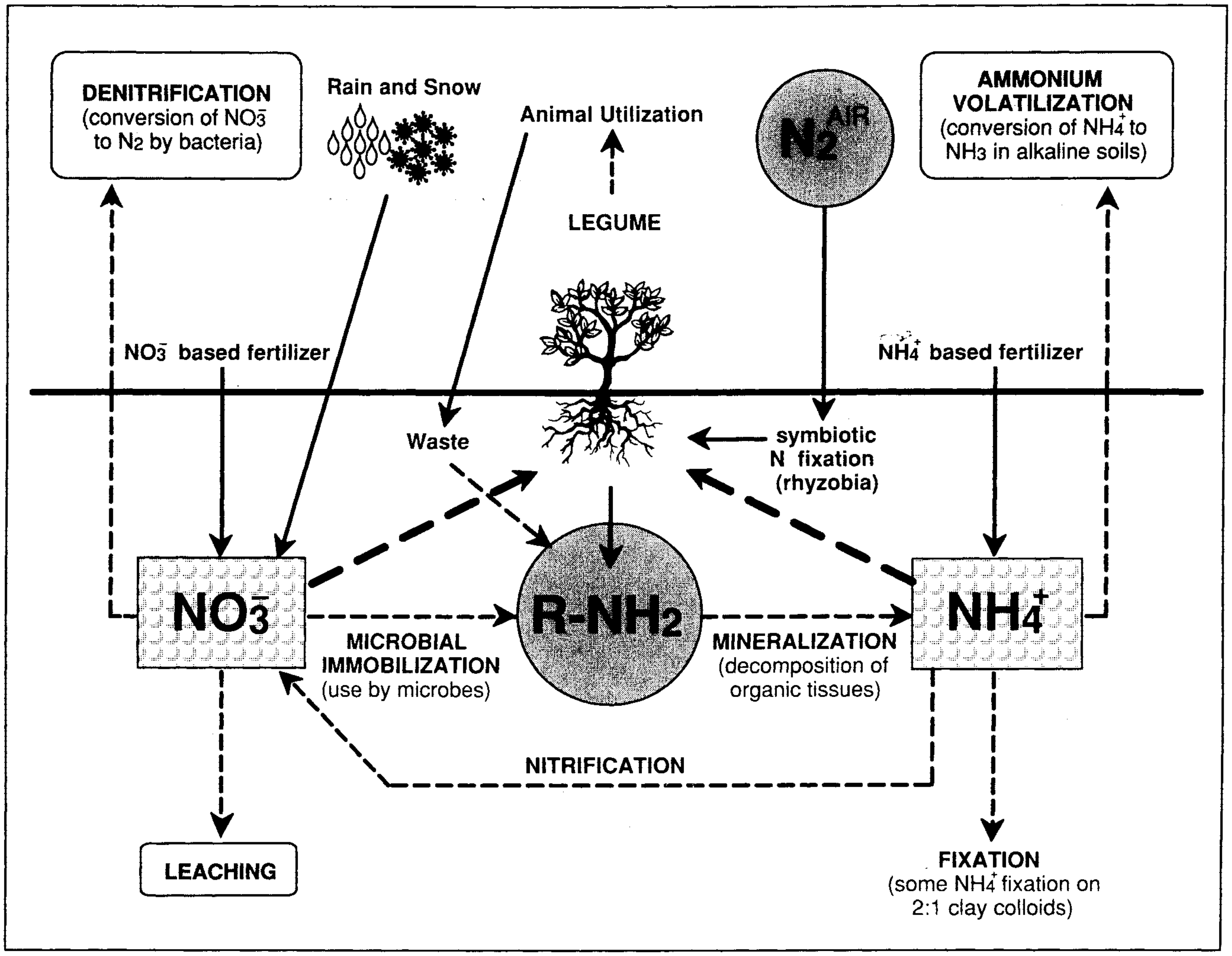
1) Lightning changes the nitrogen gas in the atmosphere to other nitrogen compounds.

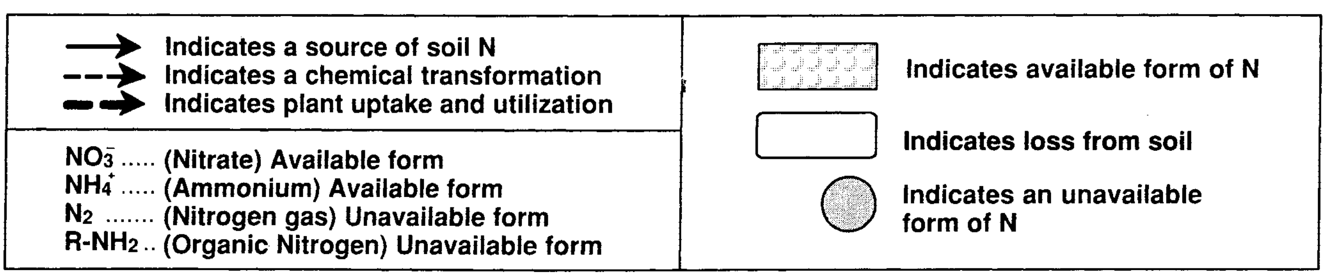
2) The action of nitrogen fixing bacteria, which convert atmospheric nitrogen to organic fixed nitrogen. This is another pathway in the nitrogen cycle.

NITROGEN TRANSFORMATIONS



THE NITROGEN CYCLE





CONVERSION FACTORS FOR NITRATE-NITROGEN ANALYSIS

There is much confusion about the relationship among:

1) nitrate and nitrate-nitrogen

2) parts per million (ppm) and percent (%) nitrogen

3) ppm and lbs/acre (kg/hectare) in soil nitrate analysis

When reporting, interpreting and analyzing nitrate, it is important to be comfortable with converting back and forth between the various units of measure.

NITRATE VERSUS NITRATE-NITROGEN

There is a mathematical relationship between nitrate (NO_3^-) and nitrate-nitrogen (NO_3–N), just as there is a relationship between inches and feet or centimeters and meters. This relationship is based on the chemical formula for these two substances.

The element nitrogen (N) exists in various forms and each of these forms can be measured. In a typical wastewater sample, N can be present as ammonia (NH_3), nitrate (NO_3^-), nitrite (NO_2^-) and organically as amines (R-NH_2), where R is a carbon-based structure. An analysis for total nitrogen would measure all the nitrogen, regardless of its chemical form. It would not measure a specific form like NO_3^-. If a test measures the amount of NO_3^- in a sample, but the standards calibrate the analysis to give results as NO_3–N, how does the analyst convert the measurement?

Every element has an atomic mass, based on the number of protons and neutrons within an atom of that element's nucleus. Nitrogen has 7 protons and 7 neutrons, for a total atomic mass of 14.

The oxygen atom is larger, with 8 protons and 8 neutrons in its nucleus, for a total atomic mass of 16. The nitrate ion NO_3^- is a combination of 1 nitrogen atom and 3 oxygen atoms. The total mass for nitrate is 14 + 48 = 62. So, in 62 lbs (kg) of NO_3^-, 14 lbs (kg) of N and 48 lbs (kg) of oxygen are present. This relationship can be expressed in two ways, either as 62 lbs (62 kg) of nitrate, or as 14 lbs (14 kg) of nitrate-nitrogen. Either expression is correct. Since 62/14 = 4.43, one can convert a nitrate measurement to actual nitrogen concentration. For example, 10 parts per million NO_3–N can be expressed as 10 x 4.43, or 44.3 parts per million NO_3^-. Both values indicate the same concentration in a different format. Just as 18 inches (50 cm) of rain is equivalent to 1.5 feet (0.5 meters), 10 ppm NO_3–N is equivalent to 44.3 ppm NO_3^-.

The following table lists convenient conversion factors. Also listed is a factor for converting NO_3^- and NO_3–N to potassium nitrate (KNO_3) concentration. Expressing N as potassium nitrate is common when potentially toxic levels of nitrate exist in forages for ruminant livestock (cattle, sheep, etc). The equivalent values in the table are based on formula weight.

NITRATE CONVERSION FACTORS

Nitrate (NO_3^-) = Nitrate-Nitrogen (NO_3–N) x 4.4
Nitrate (NO_3^-) = Potassium Nitrate (KNO_3) x 0.6

Nitrate-Nitrogen (NO_3^-–N) = Nitrate (NO_3^-) ÷ 4.4
Nitrate-Nitrogen (NO_3^-–N) = Potassium Nitrate (KNO_3) x 0.14

Potassium Nitrate (KNO_3) = Nitrate (NO_3^-) x 1.6
Potassium Nitrate (KNO_3) = Nitrate-Nitrogen (NO_3–N) x 7.0

These conversion factors work whether values are expressed as parts per million, pounds per acre kg/hectare percent (%), or other common units.

Conversion Example
A feed sample has 1,350 ppm NO_3^-–N. The value is reported as: **a)** NO_3^- and **b)** KNO_3.

So, (1,350 ppm NO_3^-–N) x (4.4) = 5,940 ppm NO_3^-; and (1,350 ppm NO_3^-–N) x (7) = 9,450 ppm KNO_3. All three values are the same concentration of nitrogen.

PARTS PER MILLION VERSUS PERCENT

Parts per million is the same as milligrams (mg) of a substance in 1 kilogram of a mixture. Parts per million is also used to express pounds of a nutrient present in 1,000,000 pounds of soil. As long as the ratio is based on the number or parts in a total of 1,000,000, the unit ppm may be used. For example, if there are 3,300 red flowers in a field of 1,000,000 flowers, the concentration of red flowers in this field is 3,300 ppm.

Since 10,000 is 1% of 1,000,000, one can convert ppm to percent by dividing ppm by 10,000. Conversely, to convert percent to ppm, multiply percent by 10,000. For example, 1,350 ppm is equivalent to 0.135 %.

So, one nitrate result can be expressed in six different but equivalent ways. The table below uses all six ways to indicate potentially lethal levels of nitrate (dry matter basis) in feed rations.

Potentially Lethal Nitrate Levels in Feed

	ppm	%
Nitrate (NO_3^-)	over 9,000	0.9
Nitrate-Nitrogen NO_3^-–N	over 2,100	0.21
Potassium Nitrate (KNO_3)	over 15,000	1.5

PPM VERSUS LBS/ACRE IN SOIL

Laboratories normally multiply ppm NO_3^-–N by 2 to convert it to lbs/acre NO_3^-–N. This is based on the assumption that a mineral soil weighs 2,000,000 lbs per acre furrow slice. An acre furrow slice is one acre of soil (43,560 square feet) at a depth of 6.67 inches (average furrow depth). However, this conversion is not truly accurate because the depth of a furrow slice varies, as does the depth of a soil sample. A better conversion is based on the average weight of one acre of mineral soil to a depth of one inch equals 300,000 lbs. Using this, the conversion is:

ppm NO_3^-–N as analyzed x 0.3 x depth of soil sample (inches) = lbs/acre

For example, if a soil sample was sampled to a depth of 12 inches, and the analysis showed 16 ppm NO_3^-–N, then 16 x 0.3 x 12 = 57.6 lbs NO_3^-–N/acre.

A Final Word of Caution

Nitrogen is available to plants in two major forms. The form most likely to be abundant is nitrate. The ammonium ion (NH_4^+) is also available. However, most soil analyses for available N measure only nitrate. This is usually adequate for fertilizer recommendations since ammonium levels are normally low **except in soils recently fertilized with nitrogen.**

Most nitrogen fertilizers contain a lot of ammonium. Under normal growing conditions, when soils are warm, ammonium converts to nitrogen in 2-3 weeks, making nitrate the most abundant form of soil nitrogen.

SOIL pH

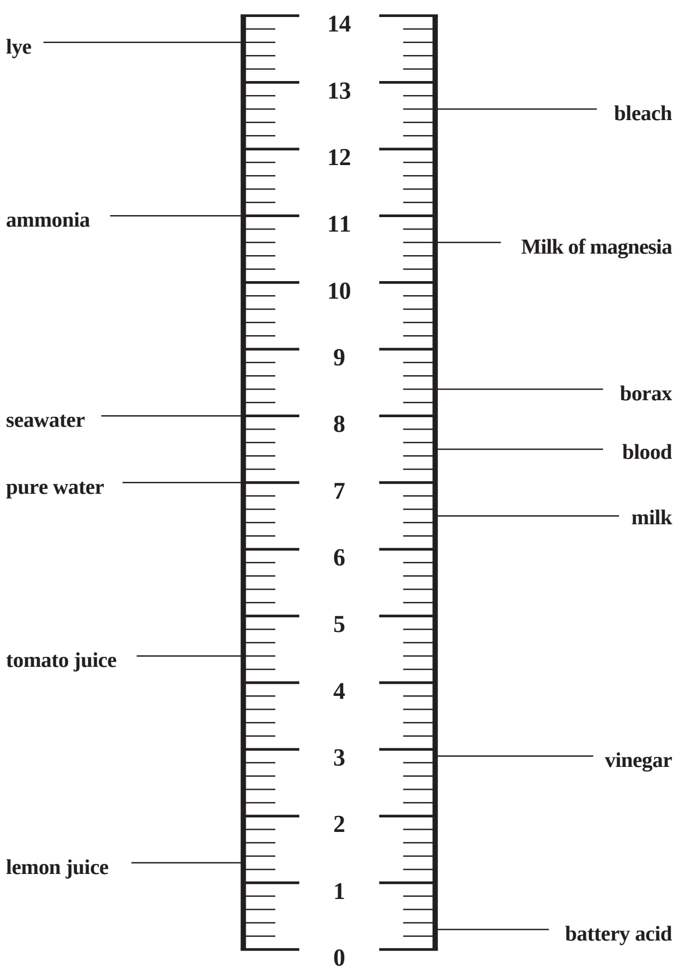
WHAT IS pH?

pH measures the ratio of acid ions (H^+) to base ions (OH^-). A system that has more H^+ ions than OH^- ions is acidic. A system with more OH^- than H^+ ions is basic (alkaline). Equal ratios of H^+ and OH^- ions result in a neutral system.

The pH scale is a tool that indicates the number of hydrogen ions in a solution. A pH of 7 is neutral, a pH greater than 7 is alkaline, and a pH less than 7 is acidic. A system with equal amounts of H^+ and OH^- ions has a 1:1 ratio of acid to base.

Each step on the scale, from 0 to 14, indicates a 10-fold change in the concentration of hydrogen ions. A system with a pH of 6 has a 10:1 ratio of acid to base. A system with a pH of 8 a has a 1:10 ratio of acid to base. Since a pH of 4.0 is three increments from 7.0, a system with a pH of 4.0 is 1,000 times more acidic than a system with a pH of 7.0 and 10,000 times more acidic than a system with a pH of 8.0.

pH of Some Common Substances



WHY IS pH IMPORTANT?

pH is important because it influences:

1) availability of plant nutrients (*see Soil pH and its Affects on Nutrient Availability*).

2) the solubility of toxic nutrients in the soil.

3) soil microbial activity.

4) physical breakdown of root cells.

5) the cation exchange capacity in soils whose colloids (clay/humus) are pH dependent.

Yearly monitoring of pH is important to good crop management. This is especially true for soils that tend to become acidic, and for soils with a coarse (sandy) texture. The following table indicates some conditions associated with pH levels in the soil and their relation to crop production.

Soil pH Levels and Associated Conditions

Determining soil pH helps isolate possible or existing problems for crop management. A range of 6.5-7.0 is optimum for most crops. When the pH is out of this range, problems can be expected.

Soil pH	Indications	Associated Condition
<5.5	Soil is deficient in Ca and/or Mg and should be limed (determine buffer pH)	Poor crop growth due to low cation exchange capacity (CEC) and possible Al^{3+} toxicity. Expect P deficiency.
5.5-6.5	Soil is low in lime and should be closely monitored.	Satisfactory for most crop production. P availability is being decreased.
6.5-7.5	Ideal range for crop production.	Soil CEC is near 100% base saturation.
7.5-8.4	Free lime ($CaCO_3$) exists in soil.	Usually excellent filtration and percolation of water due to high Ca content on clays. P and metal micro nutrients are becoming more available.
>8.4	Almost invariably indicates a sodic soil.	Very poor physical condition. Infiltration and percolation of soil water is very slow. Root deterioration and organic matter dissolution is possible.

SOIL ACIDITY

Soils become acidic for several reasons. Under normal conditions, lime in the soil acts as a "buffer", and neutralizes the acid introduced into the soil by rain, plant growth, fertilizer, and organic decay. Once the lime is used up, there is no longer a buffer to neutralize the acid present in the soil. When this happens, the pH decreases quickly and the soil has a high percentage of soluble exchangeable hydrogen (H^+) and aluminum (Al^{3+}). This creates a soil that is toxic to plant growth. Adding lime to acidic soil returns the buffering ability and raises the pH to a range where toxic aluminum precipitates out of the soil solution.

The most common acceptable method of determining lime requirement is to measure pH on an SMP extraction of the soil. In this method, a buffer is added to an acidic soil. The response of the soil, measured as an increase in pH, is related to the metric tons of lime (as $CaCO_3$) needed per hectare to raise the soil pH to either 6.5 or 7.0, depending on the soil manager's decision and the return on the investment in the crop.

Lime Requirement Table (U.S.)

	Tons/Acre of Pure Limestone* (as $CaCO_3$) Required to Raise Buffer pH	
Buffer pH	**To pH 7.0**	**To pH 6.5**
6.8	0.1	0.1
6.7	0.7	0.6
6.6	1.2	1.0
6.5	1.9	1.6
6.4	2.7	2.3
6.3	3.4	2.9
6.2	4.2	3.6
6.1	5.1	4.3
6.0	5.7	4.8
5.9	6.7	5.7
5.8	7.5	6.4
5.7	8.4	7.1
5.6	9.1	7.7
5.5	9.8	8.3
5.4	10.7	9.1
5.3	11.5	9.8
5.2	12.4	10.5
5.1	13.1	11.1
5.0	13.9	11.8
4.9	14.7	12.5

*Values based on tons of pure, fine CaCO3 with a calcium carbonate equivalent (CCE) of 100.

If using limestone other than 100 CCE, calculate the required tons by dividing the number of tons from the above table by the assayed CCE, expressed as a decimal percentage.

Example: If your buffer pH is 6.6, and you wish to raise the soil pH to 7.0, then add 1.2 tons/acre of 100 CCE limestone to the top 8 inches of soil. If the CCE of the limestone you want to use is 87, then apply 1.2/0.87 = 1.37 tons/acre to bring the pH to 7.0.

Lime Requirement Table (Metric)

	Metric Tons/Hectare of Pure Limestone* (as $CaCO_3$) Required to Raise Buffer pH	
Buffer pH	**To pH 7.0**	**To pH 6.5**
6.8	0.2	0.2
6.7	1.4	1.2
6.6	2.4	2.0
6.5	3.8	3.2
6.4	5.4	4.6
6.3	6.8	5.8
6.2	8.4	7.2
6.1	10.2	8.6
6.0	11.4	9.6
5.9	13.4	11.4
5.8	15.0	12.8
5.7	16.8	14.2
5.6	18.2	15.4
5.5	19.6	16.6
5.4	21.4	18.2
5.3	23.0	19.6
5.2	24.8	21.0
5.1	26.2	22.2
5.0	27.8	23.6
4.9	29.4	25.6

*Values based on metric tons of pure, fine CaCO3 with a calcium carbonate equivalent (CCE) of 100.

If using limestone other than 100 CCE, calculate the required metric tons by dividing the number of metric tons from the above table by the assayed CCE, expressed as a decimal percentage.

Example: If your buffer pH is 6.6, and you wish to raise the soil pH to 7.0, then add 2.4 metric tons/ha of 100 CCE limestone to the top 20 cm of soil. If the CCE of the limestone you want to use is 87, then apply 2.4/0.87 = 2.76 metric tons/ha to bring the pH to 7.0.

ALKALINE SOILS

In arid and semi-arid regions, native lime content in the soil is usually high enough to create a calcareous condition. Calcareous soils contain free particles of calcium and/or magnesium carbonate. These soils have a pH greater than 7.5 and will visibly effervesce (fizz) when 10% hydrochloric acid (muriatic acid) is added dropwise to the soil.

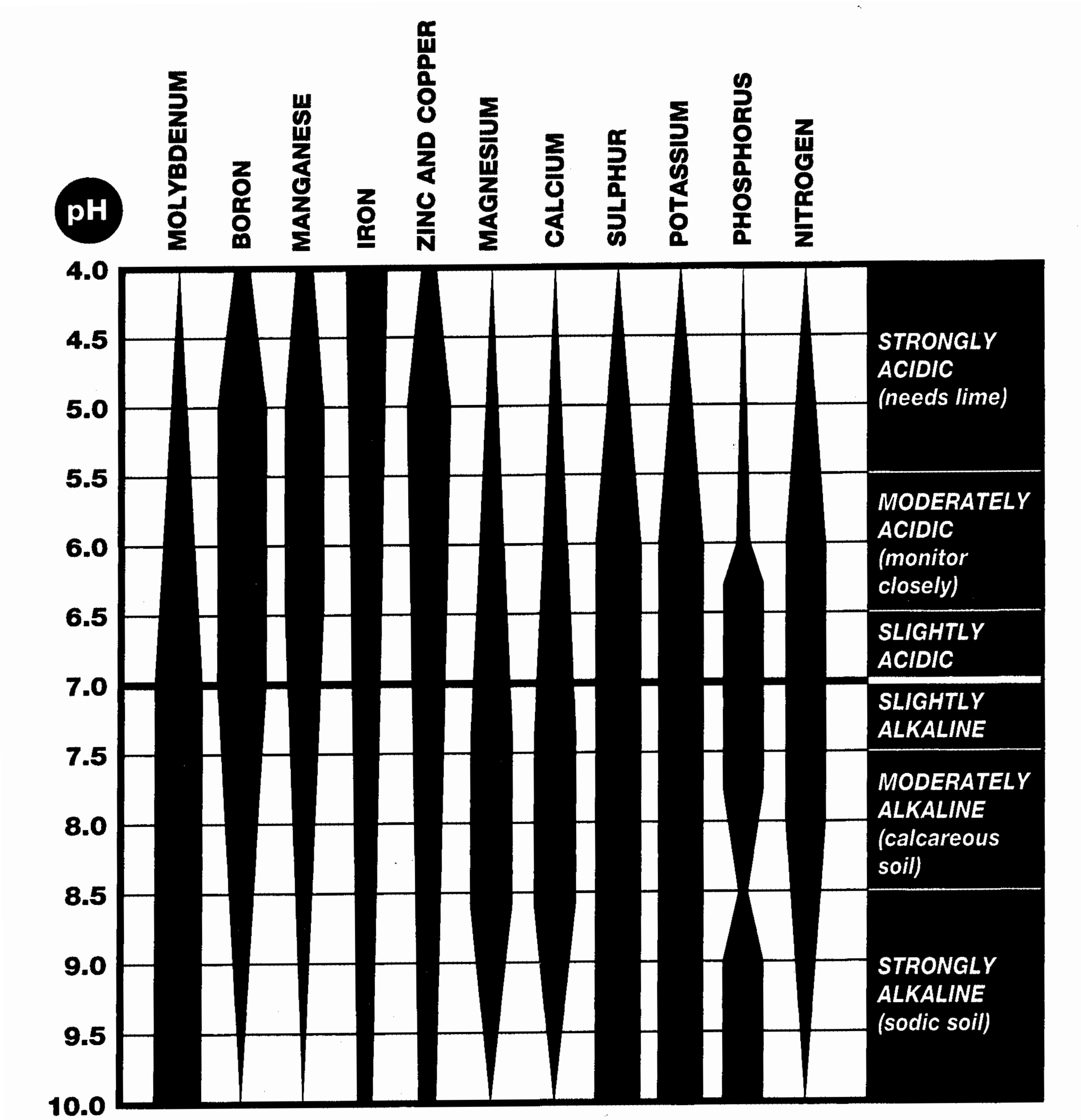
Alkaline soils can affect the availability and efficiency of phosphorus and many metal micronutrients as well as the length of time that herbicides remain in the soil. Banding phosphorus in row crops and applying micronutrients in chelated form can often help overcome these conditions.

Adding sulfur to calcareous soil to reduce the pH is not very economical. It would actually take many tons (metric tons) of elemental sulfur per acre or hectare to neutralize a medium textured soil with only 2% lime. The cost to do this is very high, so other practices should be considered. Such practices include banding fertilizer nutrients affected by the alkaline pH and/or using chelated micronutrients where alkaline conditions create deficiencies.

In soils that don't contain lime where the pH is greater than 8.4 due to high exchangeable sodium (not a calcareous condition), adding gypsum can reduce the pH. This will also increase water infiltration and percolation. If native lime is present in the soil, applying an oxidizable source of sulfur such as sulfuric acid can improve the soil pH.

Soil pH and Its Affects on Nutrient Availability

The following illustration shows the degree of nutrient availability based on soil pH.



SOIL TEST CALIBRATION

Soil tests predict the amount of plant nutrients needed to supply crops with 100% of the nutrient requirements. Some soils are very low in certain plant nutrients and require large quantities of fertilizers to supply crop needs. Conversely, some nutrients found in very high levels require no additional supplement.

Definition

A soil test is a chemical means of estimating the nutrient supplying power of a soil. The test needs to be calibrated before the results can be properly interpreted. Soil tests are calibrated by performing fertilizer rate experiments on different soils to determine the best fertilizer rate for a given soil level of nutrient. Once several fertility experiments are completed, fertilizer can be recommended based on the soil levels of nutrients. Field research is necessary before soil test values can be used to suggest fertilizer rates. Agricultural Experiment Stations provide this information.

Chemical Analysis

The chemical method used to measure the available soil nutrient level must be accurate and reproducible. As the soil test values for a nutrient increase, the response of the crop to additional fertilization decreases and reaches a point of diminishing returns.

Correlation and Interpretation

All nutrient soil test values must correlate with crop growth from fields of known response. The experimental site must have the fertilizer nutrient as the only variable. Such variables as plant population, planting pattern, tillage practices, variety, planting date, soil and rainfall/irrigation must be identical in time, quality, and quantity. For example, when an experiment is carried out on a "P" (phosphorus) responding soil, and one plot is fully fertilized while another has everything except "P", the difference in growth rate can be measured as the final yield per unit area.

Fertilizer Recommendations

The soil test indicates the nutrient level in the soil. It indicates nothing about the potential yield of the soil, the season, the management practices, or the amount of fertilizer needed. The accuracy of the test interpretation is based on the type and quality of the field research. Most of the correlation research for soil testing in the United States is conducted by the Agricultural Experiment Stations.

To determine the level of fertilization, economic considerations are important. To make an economic judgement it is necessary to estimate the crop yield response and value. Because this is difficult to do, it is best to use average yield responses and prices. Therefore, the final fertilizer recommendations depend on accurate soil test analysis and on interpretation of the test results.

Of Special Note

The following fertilizer recommendations for nitrogen, phosphorus, and potassium are only guidelines. The recommendations are based on the type of research mentioned above, and is available to the general public. Hach Company is providing this information solely as a service and assumes no responsibility for its accuracy or application.

NITRATE FERTILIZER RECOMMENDATIONS

Plants absorb nitrate from the soil solution and convert it to amino acids for use in plant growth. Nitrate is the last break down product in the aerobic nitrogen cycle before it is taken up by plants. Nitrate is soluble and easily extracted from the soil. The total amount measured by the soil test is usually available to the crop. Nitrogen recommendations are made by assuming 100% of the nitrate is available in the surface soil and about 75% is available from the subsoil with a few exceptions shown in the table below.

Nitrogen fertilizer recommendations are made by calculating the nitrogen requirement and yield goal for the crop and subtracting the soil nitrate values from the requirement. The amount of nitrogen available from a past legume crop and/or from livestock manure must also be subtracted from the nitrogen requirement. *(See Soil Nitrogen—Calculating Nitrogen Fertilizer Application).*

Estimated Amounts of Nitrogen Available From a Past Legume Crop

LEGUME	lbs N / Acre	kg N / Hectare
A. ALFALFA	100	112
B. ALFALFA (1/2 stand)	50	56
C. ALFALFA (poor stand)	0	0
D. SOYBEANS	40	44.8
E. OTHER BEANS	25	28
F. CLOVERS	75	84

Estimated Amounts of Nitrogen Available From a Manure Application

SOURCE	lbs N / TON	kg N / Metric Ton
A. BEEF FEEDLOT	5	2.5
B. DAIRY BARN	8	4
C. POULTRY	15	7.5
D. SWINE	8	4
E. SLURRY	17	8.5

The nitrogen requirement for many common crops is shown on the next page along with the subsoil factor for converting the subsoil nitrate test to lbs of N per acre (kg of N per hectare).

The total nitrogen requirement is determined by multiplying the crop yield goal by the nitrogen requirement. All surface soil nitrate ppm readings are multiplied by 0.3 (0.133 for metric) and by the sample depth (inches or cm) to arrive at kg of N per acre (hectare). The lbs (kg) of N in the subsoil are calculated by multiplying the subsoil nitrate ppm reading by subsoil sample depth (inches or cm) and the subsoil factor. The sum of nitrogen from the surface soil and subsoil is subtracted from the calculated total nitrogen requirement. To convert the total pounds of N per acre to kilograms per hectare, multiply by 1.12. If a subsoil nitrate test is not available, assume it to be 5 ppm nitrate nitrogen for fine textured soils and 2 ppm nitrate nitrogen for sandy soils.

Nitrogen Requirement Table

CROP	Nitrogen Requirement		Subsoil* Factor	
	U.S.	**(metric)**	**U.S.**	**(metric)**
Irrigated Corn	**1.4 lbs/bu**	(2.2 kg/hL)	**0.22**	(0.1)
Dryland Corn	**1.4 lbs/bu**	(2.2 kg/hL)	**0.22**	(0.1)
Irrigated Milo	**1.4 lbs/bu**	(2.2 kg/hL)	**0.22**	(0.1)
Dryland Milo	**1.4 lbs/bu**	(2.2 kg/hL)	**0.22**	(0.1)
Popcorn	**0.031 lbs/lb**	(0.031 kg/kg)	**0.22**	(0.1)
Seed Corn	**1.6 lbs/bu**	(2.6 kg/hL)	**0.22**	(0.1)
Corn Silage	**11.9 lbs/ton**	(6.0 kg/ton (M))	**0.22**	(0.1)
Sorghum Silage	**9.5 lbs/ton**	(4.8 kg/ton (M))	**0.22**	(0.1)
Feed-Hay	**25 lbs/ton**	(12.5 kg/ton (M))	**0.22**	(0.1)
Sudan Hay	**27 lbs/ton**	(13.5 kg/ton (M))	**0.22**	(0.1)
Soybeans[1]				
Pinto Beans[1]				
Great Northern Beans[1]				
Peanuts[1]				
Winter Wheat	**2 lbs/bu**	(3.2 kg/hL)	**0.22**	(0.1)
Spring Wheat	**2.2 lbs/bu**	(3.5 kg/hL)	**0.22**	(0.1)
Oats	**1.3 lbs/bu**	(2.1 kg/hL)	**0.22**	(0.1)
Rye	**1.9 lbs/bu**	(3.0 kg/hL)	**0.22**	(0.1)
Feed Barley	**1.5 lbs/bu**	(2.4 kg/hL)	**0.22**	(0.1)
Malting Barley	**1.3 lbs/bu**	(2.1 kg/hL)	**0.3**	(0.133)
Small Grain Silage	**13 lbs/ton**	(6.5 kg//ton (M))	**0.22**	(0.1)
Small Grain Hay	**40 lbs/ton**	(20 kg/ton (M))	**0.22**	(0.1)
Alfalfa	**0**		____	
New Alfalfa[1]				
Grass Alfalfa	**20 lbs/ton**	(10 kg/ton (M))	**0.22**	(0.1)
Clover	**0**		____	
BromeGrass	**40 lbs/ton**	(20 kg/ton (M))	**0.22**	(0.1)
BermudaGrass	**40 lbs/ton**	(20 kg/ton (M))	**0.22**	(0.1)
Fescue	**40 lbs/ton**	(20 kg/ton (M))	**0.22**	(0.1)
Native Grass	**27 lbs/ton**	(13.5 kg/ton (M))	**0.22**	(0.1)
LoveGrass	**32 lbs/ton**	(16 kg/ton (M))	**0.22**	(0.1)
Cool Grass	**40 lbs/ton**	(20 kg/ton (M))	**0.22**	(0.1)
Sugar Beets	**9 lbs/ton**	(4.5 kg/ton (M))	**0.3**	(0.133)
Sunflowers	**0.05 lbs/cwt**	(0.05 kg/kg)	**0.22**	(0.1)
Potatoes	**0.5 lbs/cwt**	(0.5 kg/q)	**0.3**	(0.133)
Cotton	**0.12 lbs/lb**	(0.12 kg/kg)	**0.3**	(0.133)
Millet	**1.7 lbs/bu**	(2.7 kg/hL)	**0.22**	(0.1)
Onions	**0.25 lbs/cwt**	(0.25 lkg/q)	**0.3**	(0.133)
Melons	**1 lbs/ton**	(0.5 kg/ton (M))	**0.3**	(0.133)

[1]The nitrogen requirement for these legume crops is calculated based on the P_2O_5 requirement. Each of these legumes require nitrogen in a 1:3 ratio except pinto beans which require a 1:2 ratio. (Example: if a requirement for P_2O_5 = 90 lbs/acre (101 kg/ha), then with a 1:3 ratio, 30 lbs (34 kg) of N would be required.)
*See previous page to convert Subsoil Nitrogen test to lbs per acre or kg per hectare.

PHOSPHORUS FERTILIZER RECOMMENDATIONS

Phosphorus fertilizer recommendations are developed from phosphorus soil test calibrations and crop requirements. The actual amount of phosphorus available for a growing crop is very difficult to measure. Phosphorus is held on the surfaces of soil colloids and is precipitated as insoluble phosphorus compounds. Therefore, the soil test must estimate how quickly the phosphate will move from the colloid surfaces into the soil solution for plant uptake.

The availability of soil phosphorus is estimated from experimental data by comparing crop response to phosphorus fertilizer application with the phosphorus soil test level. After several experiments, a calibration curve is drawn that shows the amount of yield response for each soil test category.

Each soil test range is an estimate of the percent sufficiency. For example, the following table shows that a crop grown in a soil with a P soil test between 6-12 ppm P will produce 45 to 80% of the yield produced with adequate phosphorus fertilization.

Percent Sufficiency Ranges and Levels for Phosphorus Soil Tests (based on Mehlich 2 extraction)

SOIL TEST (ppm P)	Level	% Sufficiency
A. 0–5	VERY LOW	25–50
B. 6–12	LOW	45–80
C. 13–25	MEDIUM	70–95
D. 26–50	HIGH	90–100
E. 51+	VERY HIGH	100

Suggested phosphorus fertilizer rates for many crops are shown in the table “Suggested Phosphorus Fertilizer Rates.” The suggested rates of P_2O_5 per acre are developed for a standard yield as shown. If a different yield goal is desired, the P_2O_5 rate should be adjusted according to the suggestions in the right hand column of the table.

Manure application will influence the final rate of phosphorus fertilizer application. The manure application rate is multiplied by the amount of P_2O_5 per ton or metric ton for the type of manure. This amount is then subtracted from the P_2O_5 rates determined from the “Suggested Phosphorus Fertilizer Rates” recommendation table.

Estimated Amounts of Phosphorus Available From Manure Application

SOURCE	lbs P_2O_5 / TON	Kg P_2O_5 / Metric Ton
A. BEEF FEEDLOT	4	2
B. DAIRY BARN	4	2
C. POULTRY	15	7.5
D. SWINE	5	2.5
E. SLURRY	13 lbs/1000 gal.	1.6 kg/1000 liters

SUGGESTED PHOSPHORUS FERTILIZER RATES (U.S.)

Crop	Measured Soil Phosphorus 0 to 5 ppm	6 to 12 ppm	13 to 25 ppm	26 to 50 ppm	51+ ppm	Standard Yield	Adjustment for other Yield
	lbs/Acre P_2O_5 to apply:					To get:	
Irrigated Corn	70-100	45-65	25-40	0-20	0	120 bu	2 lbs/10 bu
Dryland Corn	65-90	40-50	20-35	0-20	0	95 bu	2 lbs/10 bu
Irrigated Milo	60-80	40-55	15-35	0-20	0	100 bu	2 lbs/10 bu
Dryland Milo	55-70	35-50	15-30	0-15	0	75 bu	2 lbs/10 bu
Popcorn	70-100	45-65	25-40	0-20	0	100 bu	2 lbs/10 bu
Seed Corn	70-100	45-65	25-40	0-20	0	80 bu	2 lbs/10 bu
Corn Silage	70-100	45-65	25-40	0-20	0	12 ton	1.5 lbs/ton
Sorghum Silage	70-90	45-65	25-40	0-20	0	15 ton	1.5 lbs/ton
Feed-Hay	50-65	35-50	20-35	0-20	0	3 ton	5 lbs/ton
Sudan Hay	50-65	35-50	20-35	0-20	0	3 ton	5 lbs/ton
Soybeans	50-70	35-45	20-30	0-15	0	35 bu	5 lbs/ton
Pinto Beans	50-70	35-45	20-30	0-15	0	ALL	NONE
Great North Beans	50-70	35-45	20-30	0-15	0	ALL	NONE
Peanuts	50-70	50-60	25-45	0-30	0	ALL	NONE
Winter Wheat	65-85	50-60	25-45	0-20	0	55 bu	2.5 lbs/ 10 bu
Spring Wheat	45-60	35-45	20-30	0-20	0	35 bu	2.5 lbs/ 10 bu
Oats	45-60	35-45	20-30	0-20	0	80 bu	1.5 lbs/ 10 bu
Rye	45-60	35-45	20-30	0-20	0	45 bu	2.5 lbs/ 10 bu
Feed Barley	45-60	35-45	20-30	0-20	0	60 bu	2.0 lbs/ 10 bu
Malting Barley	45-60	35-45	20-30	0-20	0	60 bu	2.0 lbs/ 10 bu
Small Grain Silage	65-85	50-60	25-45	0-20	0	8 ton	2.0 lbs/ 10 bu
Small Grain Hay	65-85	50-60	25-45	0-20	0	4 ton	4 lbs/ ton
Alfalfa	90-120	60-85	30-55	0-25	0	4 ton	5 lbs / ton
New Alfalfa	90-120	60-85	30-55	0-25	0	3 ton	5 lbs / ton
Grass Alfalfa	65-80	45-60	25-40	0-20	0	5 ton	5 lbs / ton
Clover	70-95	50-65	25-45	0-20	0	4 ton	5 lbs / ton
Bromegrass	55-70	40-55	20-35	0-20	0	3 ton	5 lbs / ton
Bermudagrass	50-65	35-45	20-30	0-20	0	3 ton	5 lbs / ton
Fescue	55-70	40-55	20-35	0-20	0	3 ton	5 lbs / ton
Native Grass	35-45	20-30	0-20	0	0	ALL	NONE
Lovegrass	45-60	35-45	20-30	0-20	0	ALL	NONE
Cool Grass	55-70	40-55	20-35	0-20	0	ton	5 lbs / ton
Sugar Beets	105-120	85-100	55-80	30-50	0	20 ton	2 lbs / ton
Sunflowers	35-45	30-35	20-30	0	0	1800 lbs	5 lbs / 600 lbs
Potatoes	130-160	100-125	60-95	20-55	0	350 cwt	1 lb / cwt
Cotton	60-75	30-45	30-45	0-30	0	500 lbs	4 lbs / 100 lbs
Millet	45-55	20-30	20-30	0-20	0	ALL	NONE
Onions	70-95	25-45	25-45	0-25	0	ALL	NONE
Melons	80-100	30-50	30-50	0-30	0	ALL	NONE
Garden	130-160	60-95	60-95	20-55	0	ALL	NONE

SUGGESTED PHOSPHORUS FERTILIZER RATES (METRIC)

Crop	Measured Soil Phosphorus 0 to 5 ppm	6 to 12 ppm	13 to 25 ppm	26 to 50 ppm	51+ ppm	Standard Yield	Adjustment for other Yield
	kg/ha P_2O_5 to apply:					To get:	
Irrigated Corn	78-112	50-73	28-45	0-22	0	42 hL	3 kg/10 hL
Dryland Corn	73-101	45-56	22-39	0-22	0	33 hL	3 kg/10 hL
Irrigated Milo	67-90	45-62	17-39	0-22	0	35 hL	3 kg/10 hL
Dryland Milo	62-78	39-56	17-34	0-17	0	26 hL	3 kg/10 hL
Popcorn	78-112	50-73	28-45	0-22	0	35 hL	3 kg/10 hL
Seed Corn	78-112	50-73	28-45	0-22	0	28 hL	3 kg /10 hL
Corn Silage	78-112	50-73	28-45	0-22	0	11 ton (M)	0.75 kg/ ton (M)
Sorghum Silage	78-101	50-73	28-45	0-22	0	14 ton (M)	0.75 kg/ ton (M)
Feed-Hay	56-73	39-56	22-39	0-22	0	3 ton (M)	2.5 kg/ton (M)
Sudan Hay	56-73	39-56	22-39	0-22	0	3 ton (M)	2.5 kg/ton (M)
Soybeans	56-78	39-50	22-34	0-17	0	12 hL	2.5 kg/ton (M)
Pinto Beans	56-78	39-50	22-34	0-17	0	ALL	NONE
Great North Beans	56-78	39-50	22-34	0-17	0	ALL	NONE
Peanuts	56-78	56-67	28-50	0-34	0	ALL	NONE
Winter Wheat	73-95	56-67	28-50	0-22	0	19 hL	4 kg/10 hL
Spring Wheat	50-67	39-50	22-34	0-22	0	12 hL	4 kg/10 hL
Oats	50-67	39-50	22-34	0-22	0	28 hL	2.4 kg/10 mL
Rye	50-67	39-50	22-34	0-22	0	16 hL	4 kg/10 hL
Feed Barley	50-67	39-50	22-34	0-22	0	21 hL	3 kg/10 hL
Malting Barley	50-67	39-50	22-34	0-22	0	21 hL	3 kg/10 hL
Small Grain Silage	73-95	56-67	28-50	0-22	0	7 ton (M)	3 kg/10 hL
Small Grain Hay	73-95	56-67	28-50	0-22	0	4 ton (M)	2 kg/ton (M)
Alfalfa	101-134	67-95	34-62	0-28	0	4 ton (M)	2.5 kg/ton (M)
New Alfalfa	101-134	67-95	34-62	0-28	0	3 ton (M)	2.5 kg/ton (M)
Grass Alfalfa	73-90	50-67	28-45	0-22	0	5 ton (M)	2.5 kg/ton (M)
Clover	78-106	56-73	28-50	0-22	0	4 ton (M)	2.5 kg/ton (M)
Bromegrass	62-78	45-62	22-39	0-22	0	3 ton (M)	2.5 kg/ton (M)
Bermudagrass	56-73	39-50	22-34	0-22	0	3 ton (M)	2.5 kg/ton (M)
Fescue	62-78	45-62	22-39	0-22	0	3 ton (M)	2.5 kg/ton (M)
Native Grass	39-50	22-34	0-22	0	0	ALL	NONE
Lovegrass	50-67	39-50	22-34	0-22	0	ALL	NONE
Cool Grass	62-78	45-62	22-39	0-22	0	1 ton (M)	2.5 kg/ton (M)
Sugar Beets	118-134	95-112	62-90	34-56	0	18 ton (M)	1 kg/ton (M)
Sunflowers	39-50	34-39	22-34	0	0	817 kg	8 kg/1000 kg
Potatoes	146-179	112-140	67-106	22-62	0	772 q	1kg/q
Cotton	67-84	34-50	34-50	0-34	0	227 kg	4 kg/q
Millet	50-62	22-34	22-34	0-22	0	ALL	NONE
Onions	78-106	28-50	28-50	0-28	0	ALL	NONE
Melons	90-112	34-56	34-56	0-34	0	ALL	NONE
Garden	146-179	67-106	67-106	22-62	0	ALL	NONE

POTASSIUM FERTILIZER RECOMMENDATIONS

Potassium fertilizer recommendations are developed from potassium soil test calibrations and crop requirements. The actual amount of available potassium (K^+) for a growing crop is estimated by measuring the exchangeable potassium level in the soil.

The availability of soil potassium is estimated from experimental data by comparing yield response from potassium fertilizer application with potassium soil test levels. After several experiments, a calibration curve can be drawn that shows the amount of yield response for each soil test category.

Each soil test range is an estimate of the percent sufficiency. The following table, for example, shows that a crop grown in a soil with a K^+ soil test between 41-80 ppm K^+ will produce 45 to 80% of the yield produced with adequate potassium fertilization.

Percent Sufficiency Ranges and Levels For Potassium Soil Tests (based on Mehlich 2 extraction)

Soil Test Level (ppm K)	Level	% Sufficiency
A. 0 - 40	VERY LOW	20 - 50
B. 41 - 80	LOW	45 - 80
C. 81 - 120	MEDIUM	70 - 95
D. 121 - 200	HIGH	90 - 100
E. 200+	VERY HIGH	100

Potassium fertilizer rates suggested for many crops are shown in the tables on the next pages. The suggested rates of K_2O per acre or hectare are developed for a standard yield as shown. If a different yield goal is desired, the K_2O rate should be adjusted according to the suggestions in the right hand column in the recommendation table.

Manure application will influence the final rate of potash fertilizer application. The manure application rate is multiplied by the amount of K_2O per ton or metric ton for the type of manure. This amount is then subtracted from the K_2O rates determined from the recommendation table.

Estimated Amounts of Potassium Available From Manure Application

SOURCE	lbs K_2O/TON	kg K/Metric Ton
A. BEEF FEEDLOT	10	5
B. DAIRY BARN	12	6
C. POULTRY	15	7.5
D. SWINE	12	6
E. SLURRY	34 lbs/1000 gal	17 kg/1000 liters

SUGGESTED POTASSIUM FERTILIZER RATES (U.S.)

Crop	Measured Soil Potassium					Standard Yield	Adjustment for other Yield
	0-40 ppm	42-80 ppm	81-120 ppm	120-200 ppm	200+ ppm		
	lbs/Acre K_2O to apply:					To get:	
Irrigated Corn	105-180	60-100	35-55	15-30	0	120 bu	5 lbs/20 bu
Dryland Corn	100-175	55-95	30-50	0-25	0	95 bu	5 lbs/20 bu
Irrigated Milo	75-120	50-70	30-45	15-30	0	100 bu	5 lbs/20 bu
Dryland Milo	70-115	45-65	25-40	0-20	0	75 bu	5 lbs/20 bu
Popcorn	90-145	55-85	30-50	15-30	0	100 bu	5 lbs/20 bu
Seed Corn	105-180	60-100	35-55	15-30	0	80 bu	5 lbs/20 bu
Corn Silage	135-220	80-130	50-75	30-45	0	12 ton	2 lbs/ton
Sorghum Silage	135-220	80-130	50-75	30-45	0	15 ton	2 lbs/ton
Feed-Hay	80-130	50-75	30-45	0-25	0	4 ton	6 lbs/ton
Sudan Hay	80-130	50-75	30-45	0-25	0	4 ton	6 lbs/ton
Soybeans	90-145	55-85	30-50	0-25	0	40 bu	6 lbs/ton
Pinto Beans	90-145	55-85	30-50	0-25	0	ALL	NONE
Great North Beans	90-145	55-85	30-50	0-25	0	ALL	NONE
Peanuts	90-145	55-85	30-50	0-25	0	ALL	NONE
Winter Wheat	60-100	35-55	20-30	0-20	0	45 bu	3 lbs/10 bu
Spring Wheat	60-100	35-55	20-30	0-20	0	40 bu	3 lbs/10 bu
Oats	60-100	35-55	20-30	0-20	0	80 bu	2 lbs/10 bu
Rye	60-100	35-55	20-30	0-20	0	45 bu	3 lbs/10 bu
Feed Barley	60-100	35-55	20-30	0-20	0	60 bu	5.0 lbs/20 bu
Malting Barley	60-100	35-55	20-30	0-20	0	60 bu	5.0 lbs/20 bu
Small Grain Silage	70-120	45-65	25-40	0-20	0	7 ton	2.0 lbs/10 bu
Small Grain Hay	70-120	45-65	25-40	0-20	0	3 ton	5 lbs/ton
Alfalfa	130-210	80-125	45-75	25-40	0	4 ton	6 lbs/ton
New Alfalfa	130-210	80-125	45-75	25-40	0	3 ton	6 lbs/ton
Grass Alfalfa	130-210	80-125	45-75	25-40	0	5 ton	6 lbs/ton
Clover	130-210	80-125	45-75	25-40	0	4 ton	6 lbs/ton
Bromegrass	85-150	50-75	30-45	0-25	0	3 ton	4 lbs/ton
Bermudagrass	120-210	70-115	40-65	20-35	0	3 ton	4 lbs/ton
Fescue	85-150	50-75	30-45	0-25	0	3 ton	4 lbs/ton
Native Grass	55-100	30-50	15-25	0	0	ALL	NONE
Lovegrass	70-120	40-65	25-35	0-20	0	ALL	NONE
Cool Grass	85-150	50-75	30-45	0-25	0	3 ton	4 lbs/ton
Sugar Beets	130-210	80-125	45-75	25-40	0	20 ton	2.5 lbs/ton
Sunflowers	55-100	30-50	15-35	0	0	1800 lbs	12 lbs/1000 lbs
Potatoes	135-225	80-130	50-75	25-45	0	350 cwt	12 lbs/cwt
Cotton	90-145	55-85	30-50	0-25	0	500 lbs	4 lbs/100 lbs
Millet	60-100	35-55	20-30	0-20	0	ALL	NONE
Onions	135-220	80-130	50-75	30-45	0	ALL	NONE
Melons	135-220	80-130	50-75	30-45	0	ALL	NONE
Garden	135-225	80-130	50-75	25-45	0	ALL	NO

SUGGESTED POTASSIUM FERTILIZER RATES (METRIC)

Crop	Measured Soil Potassium 0-40 ppm	42-80 ppm	81-120 ppm	120-200 ppm	200+ ppm	Standard Yield	Adjustment for other Yield
	kg/ha K_2O to apply:					To get:	
Irrigated Corn	118-202	67-112	39-62	17-34	0	42 hL	4 kg/10 hL
Dryland Corn	112-196	62-106	34-56	0-28	0	33 hL	4 kg/10 hL
Irrigated Milo	84-134	56-78	34-50	17-34	0	35 hL	4 kg/10 hL
Dryland Milo	78-129	50-73	28-45	0-22	0	26 hL	4 kg/10 hL
Popcorn	101-162	62-95	34-56	17-34	0	35 hL	4 kg/10 hL
Seed Corn	118-202	67-112	39-62	17-34	0	28 hL	4 kg/10 hL
Corn Silage	151-247	90-146	56-84	34-50	0	11 ton (M)	1 kg/ton (M)
Sorghum Silage	151-247	90-146	56-84	34-50	0	14 ton (M)	1 kg/ton (M)
Feed-Hay	90-146	56-84	34-50	0-28	0	4 ton (M)	3 kg/ton (M)
Sudan Hay	90-146	56-84	34-50	0-28	0	4 ton (M)	3 kg/ton (M)
Soybeans	101-162	62-95	34-56	0-28	0	14 hL	3 kg/ton (M)
Pinto Beans	101-162	62-95	34-56	0-28	0	ALL	NONE
Great North Beans	101-162	62-95	34-56	0-28	0	ALL	NONE
Peanuts	101-162	62-95	34-56	0-28	0	ALL	NONE
Winter Wheat	67-112	39-62	22-34	0-22	0	16 hL	5 kg/10 hL
Spring Wheat	67-112	39-62	22-34	0-22	0	14 hL	5 kg/10 hL
Oats	67-112	39-62	22-34	0-22	0	28 hL	3 kg/10 hL
Rye	67-112	39-62	22-34	0-22	0	16 hL	5 kg/10 hL
Feed Barley	67-112	39-62	22-34	0-22	0	21 hL	4 kg/10 hL
Malting Barley	67-112	39-62	22-34	0-22	0	21 hL	4 kg/10 hL
Small Grain Silage	78-134	50-73	28-45	0-22	0	6 ton (M)	3 kg/10 hL
Small Grain Hay	78-134	50-73	28-45	0-22	0	3 ton (M)	2.5 kg/ton (M)
Alfalfa	146-235	90-140	50-84	27-45	0	4 ton (M)	3 kg/ton (M)
New Alfalfa	146-235	90-140	50-84	27-45	0	3 ton (M)	3 kg/ton (M)
Grass Alfalfa	146-235	90-140	50-84	27-45	0	5 ton (M)	3 kg/ton (M)
Clover	146-235	90-140	50-84	27-45	0	4 ton (M)	3 kg/ton (M)
Bromegrass	95-168	56-84	34-50	0-28	0	3 ton (M)	2 kg/ton (M)
Bermudagrass	134-235	78-129	45-73	22-39	0	3 ton (M)	2 kg/ton (M)
Fescue	95-168	56-84	34-50	0-28	0	3 ton (M)	2 kg/ton (M)
Native Grass	62-112	34-56	17-28	0	0	ALL	NONE
Lovegrass	78-134	45-73	28-39	0-22	0	ALL	NONE
Cool Grass	95-168	56-84	34-50	0-28	0	3 ton (M)	2 kg/ton (M)
Sugar Beets	146-235	90-140	50-84	28-45	0	18 ton (M)	1.3 kg/ton (M)
Sunflowers	62-112	34-56	17-39	0	0	817 kg	12 kg/1000 kg
Potatoes	151-252	90-146	56-84	28-50	0	772 q	12 kg/q
Cotton	101-162	62-95	34-56	0-28	0	227 kg	4 kg/100 q
Millet	67-112	39-62	22-34	0-28	0	ALL	NONE
Onions	151-247	90-146	56-84	34-50	0	ALL	NONE
Melons	151-247	90-146	56-84	34-50	0	ALL	NONE
Garden	152-252	90-146	56-84	28-50	0	ALL	NO

IRRIGATION WATER QUALITY

There are four major criteria to consider when evaluating irrigation water quality:

1) The concentration of soluble salts (salinity hazard)

2) The amount of sodium in water compared to other cations (sodium hazard)

3) The concentration of toxic elements that may inhibit plant growth or be an environmental hazard

4) The nutritional benefit resulting from nutrients such as nitrate, phosphate, and sulfate which may be present in the irrigation water in significant amounts.

Of these criteria, salinity and/or sodium hazard is the most prevalent problem associated with irrigation water. The Hach Soil and Irrigation Water Test Kit provides chemistries for analyzing soluble salts, sodium, nitrate, and phosphate.

SALINITY HAZARD

The definition of salinity in irrigation water is the total sum of dissolved inorganic ions and molecules. The major positive ions (cations) in salinity are calcium (Ca^{2+}), magnesium (Mg^{2+}), and sodium (Na^{+}). The major negative ions (anions) are chloride (Cl^{-}), sulfate (SO_4^{2-}), and bicarbonate (HCO_3^{-}). Other ions may be present, but normally are not concentrated enough to affect the total salinity.

All irrigation waters contain some dissolved salts. When irrigation water contains excess dissolved salts, the soil being irrigated can accumulate those salts due to evapo-transpiration and/or poor drainage. This process increases the tendency of water to be held by the soil instead of being absorbed by the roots (this tendency is called osmotic pressure).

Another force affecting water adsorption by plant roots is matrix potential, which is simply the attraction of soil solids (matrix) for water. This force affects how much moisture the soil retains and the free movement of water in the soil.

These two forces can cause a physiological drought. Even if the soil contains plenty of moisture, the plants wilt because they cannot absorb enough water to replace the water lost by transpiration. The combination of osmotic pressure and the matric potential resulting from soil particles decrease the root's ability to absorb enough water. As soils dry out due to evapotranspiration, the soil water becomes more saline and less available to plants.

The salinity hazard of irrigation water is measured routinely by determining the electrical conductivity (EC), which is usually reported as microSiemens per centimeter (µS/cm). When irrigating with water high in EC (salinity hazard), the excess salts introduced by irrigation must be routinely flushed out of the soil by providing adequate drainage and enough excess irrigation water to provide for plant requirements and leaching.

SODIUM HAZARD

Irrigation waters containing high amounts of sodium (Na) salts versus calcium (Ca) and/or magnesium (Mg) salts can create a build-up of exchangeable sodium in the soil. This build-up results in the dispersion of soil colloidal particles and an increase in soil pH to values above 8.5. As soil colloidal particles disperse, the soil becomes increasingly resistant to water infiltration and percolation. These sodium-affected soils become hard and compact when dry and very resistant to water penetration due to dispersion and swelling when wet. The more clay the soil contains, the more subject the soil is to dispersion.

Sodium buildup is predicted by the sodium adsorption ratio (SAR) vs the total salinity (EC_{iw}) of the irrigation water. The formula for determining SAR is below. In addition, the nomogram on the next page can be used to determine SAR based on Ca + Mg meq/L and Na meq/L.

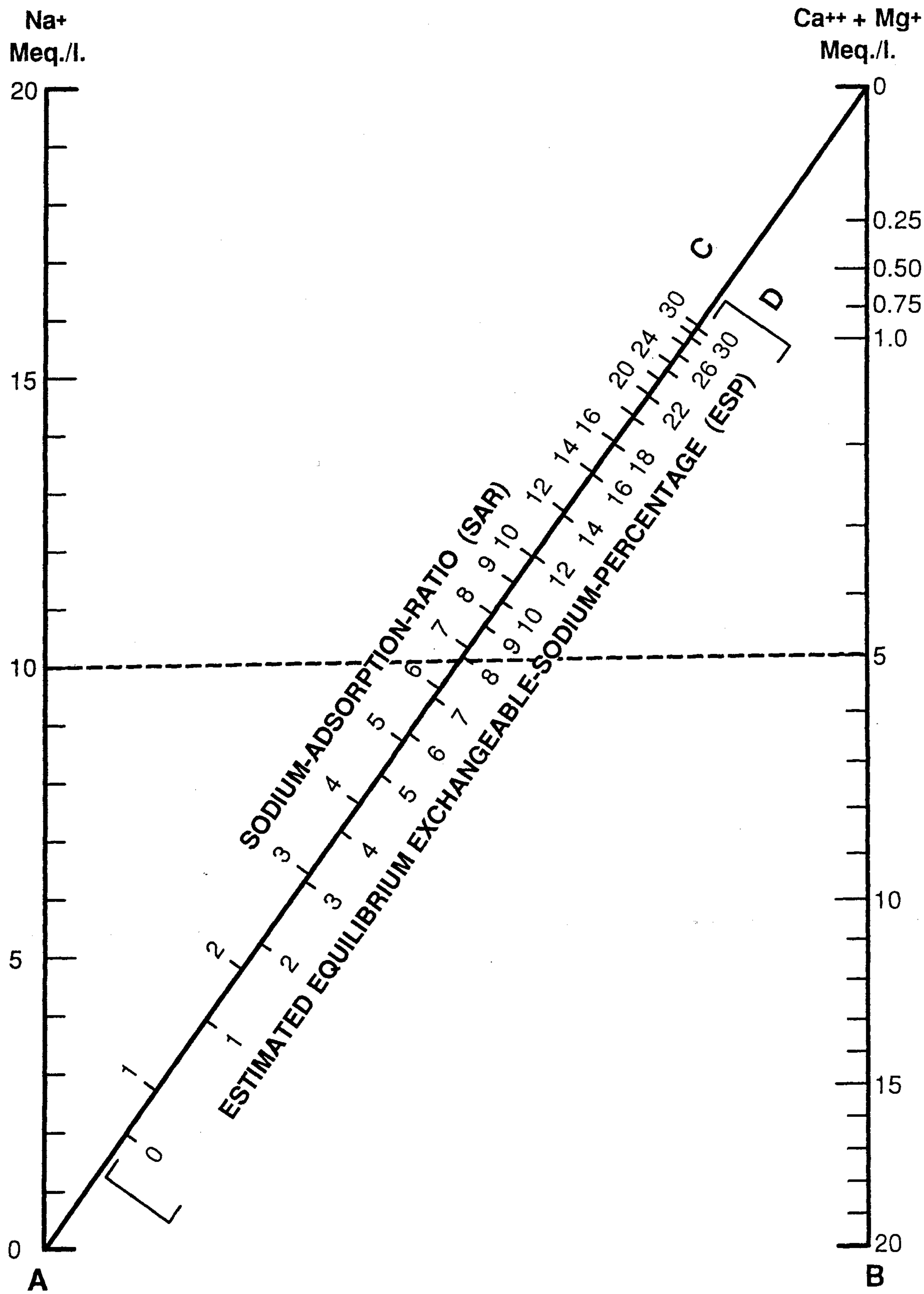
$$\text{SAR} = \frac{Na^{+}\text{ meq/L}}{\sqrt{\dfrac{(Ca^{2+} + Mg^{2+}\text{ meq/L})}{2}}}$$

Example:
Suppose the sodium concentration in irrigation water is 10 meq/L and the calcium + magnesium concentration is 5 meq/L. Using the formula from above the SAR is:

$$\frac{10\text{ meq/L}}{\sqrt{\dfrac{5\text{ meq/L}}{2}}} = \frac{10}{1.58} = 6.3$$

Example: Using the nomogram (see next page also)
Find the sodium concentration on the left side (line A) of the nomogram; mark it with a small dot. Find the calcium + magnesium concentration on the right side (line B); mark it with a small dot. Using a straight edge, draw a line connecting the two dots. The point where the line connecting the dots crosses the line with the sodium adsorption scale (line C) is the SAR value. The dashed line on the following nomogram is an example using the values given above.

NOMOGRAM TO DETERMINE SAR OF IRRIGATION WATER



TOXIC ELEMENTS

Some elements are highly toxic to crop growth. Because different crops vary in their tolerance for toxic elements, the actual toxic concentration of the element varies from crop to crop. Elements which induce toxic effects include boron, sodium, and heavy metals (i.e., arsenic, cobalt, copper, lead, nickel, and zinc).

In addition to toxic risk, many elements required for plant growth create environmental hazards if present in excess. While waters high in nitrates and heavy metals can harm humans, waters high in phosphates can result in eutrophication of natural waters. The Hach Soil and Irrigation Water Test Kit provides chemistries and instrumentation for nitrate and phosphate analysis. However, if problems resulting from toxic elements are suspected, more extensive analytical systems can be purchased from Hach Company.

NUTRITIONAL BENEFIT

High levels of nitrates and phosphates in irrigation water can create environmental concerns, but these waters can aid crop growth as effectively as a fertilizer application. An irrigation water sample containing 10 ppm (10 mg/L) of nitrate-nitrogen would provide 27 lbs of nitrogen per acre foot of water [17 kg/1000 m^3 (30 kg of nitrogen per hectare covered by 30 cm of water)]. This relationship can be applied to any nutrient being considered as a benefit. The analyst must first determine the ppm of the nutrient in question and then multiply by 2.7 to convert to lbs per acre foot of water (by 1.8 to convert to kg per 30 cm of water covering one hectare.

The Hach Soil and Irrigation Water Test Kit provides chemistries and instrumentation for nitrate and phosphate analysis. If the analyst is interested in other nutrients, a water sample can be sent to a competent laboratory for precise analysis or additional testing capabilities can be purchased from Hach Company.

USE OF SALINE IRRIGATION WATER

Since the publication of *Agriculture Handbook No. 60* in 1954, the United States Salinity Laboratory in Riverside, California has done extensive research on salinity and sodicity. The interpretive data in this book assumed large amounts of high quality irrigation water would be available. However, high quality water is now becoming scarce and we need to re-evaluate using water that was once considered too saline or sodic to use.

A paper published by Dr. James Rhoades, the Salinity Laboratory director, provides an update on the use of salt and sodium affected waters for irrigation. This paper, "Using Saline Waters for Irrigation", was presented at the International Workshop on Salt Affected Soils of Latin America in October of 1983. The paper discusses the effects of saline water on a given crop (measured as relative crop yield) and/or quantifying the harmful effects on a given crop if saline irrigation water is used.

When irrigating with saline water, larger volumes must be applied so the residual salts left by previous irrigation are washed out. The grower can determine if leaching is feasible by calculating the leaching requirement based on the salinity of the water and the salt tolerance of the crop. The feasibility is based on how well the soil can drain the excess water and/or whether the predicted yield loss is tolerable. If the leaching requirement is not possible, the grower could either choose a more salt tolerant crop or accept lower crop yields.

LEACHING REQUIREMENT

The leaching requirement (LR) is water in excess of the evapotranspiration rate required by the crop. The leaching requirement is a percentage only. A leaching requirement of 20 indicates that 20% more water must be applied than required by the normal evapotranspiration rate. The increased water inhibits salinity buildup that could harm the crop.

The amount of saline buildup in a non-saline soil depends on the irrigation water salinity and the volume of water not required by evapotranspiration that moves through the root zone. Adequate drainage is necessary so the water can leach the soluble salts below the root zone. The irrigation water that passes through the root zone is called the leaching fraction (LF). Leaching requirement is what is desired and calculated; leaching fraction is what really occurs. If a soil can adequately drain the irrigation volume required for the LR, then the LF and LR are equal.

HIGH FREQUENCY VERSUS CONVENTIONAL IRRIGATION WITH SALINE WATER

The volume of the leaching fraction is based on either high frequency irrigation or conventional irrigation. With high frequency irrigation, the soil is kept near field capacity and the matric potential is kept very low.

Using conventional irrigation, the soil becomes relatively dry before being irrigated. As the soil dries, the matric and osmotic potential of soil water increases, causing stress on the plants because water is more difficult to absorb. Water at field capacity requires only 1/3 atmosphere of suction to be absorbed by plants. Water at permanent wilting point requires 15 atmospheres of suction for absorption.

Saline waters are more usable if high frequency irrigation is practiced. The problem is that more water means more salts are added to the soil if a leaching fraction is not maintained.

RELATIVE YIELDS USING SALINE IRRIGATION WATER

Relative yield (Yr) indicates the expected yield, or inversely the yield lost, by using saline water. Relative yield depends on:

a) the conductivity of the irrigation water (EC_{iw})

b) the actual leaching fraction

c) the salt tolerance of the growing crop.

Yr is calculated based on the conductivity of the saturated paste extract (EC_e) and the salt tolerance of the crop:

$$Yr = 100 - [b(EC_e - a)]$$

Where:

a = salinity threshold of the crop

b = % yield decrease per unit of salinity increase above the threshold (slope) for a crop

The values a and b are obtained from tables by Mass and Hoffman (pages 31-36). Reprints of the abstract "Salt Tolerance of Plants" are available by writing to:

E.V. Maas
U.S. Salinity Laboratory
USDA Agricultural Research Service
4500 Glenwood Drive
Riverside, CA, U.S.A 92501

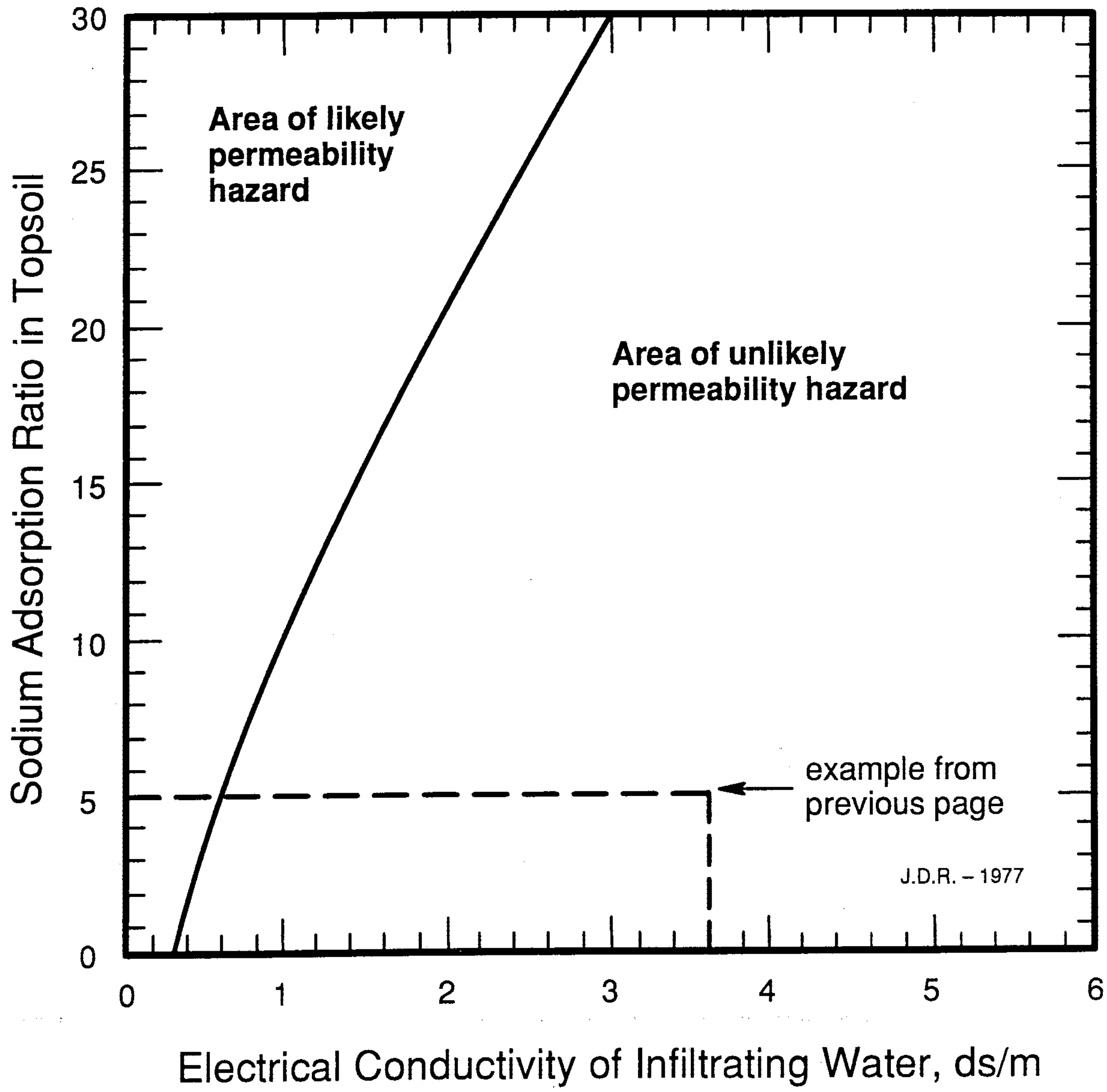
Permeability Hazard

Finally, the grower should determine the possibility of sodium buildup, which can cause permeability problems. This is done graphically with the sodium adsorption ratio (SAR) plotted on one axis and the irrigation water salinity plotted on the other axis. *See the Permeability Hazard Chart on the next page.*

Example

For example, the electrical conductivity of the irrigation water is 3.6 dS/m and the sodium adsorption ratio is 5.1. Draw a straight vertical line up from the dS/m value. Then draw a straight horizontal line from the SAR value until it meets the line from the dS/m value. If the lines meet on the right side of the curved line, permeability is not likely to be a problem. If the lines meet on the left side of the curved line, sodium build-up in the soil is likely to cause permeability problems. In this example, permeability should not be a problem.

PERMEABILITY HAZARD CHART



Dr. Rhoades has developed a computer program called "wetsuit" that computes and interprets irrigation water data. A simplified version of his scheme is used in the following example.

Example

Data from analysis:

- EC_{iw} = 3600 µS/cm (also expressed as 3.6 mS/cm, 3.6 ds/M, 3600 µMhos/cm, or 3.6 µMhos/cm)
- Ca + Mg = 20 meq/L
- Estimated Na meq/L = [(3.6 x 10) - 20] = 16 meq/L Na *See calculation for determination of estimated Na in the SIW-1 Soil and Irrigation Water Manual*
- Crop—Wheat (moderately tolerant; has threshold salinity value of 6.0 mS/cm). *See Salt Tolerance Tables on pages 31 to 36 to determine threshold salinity.*
- Irrigation Method—Conventional

Interpretation Strategy

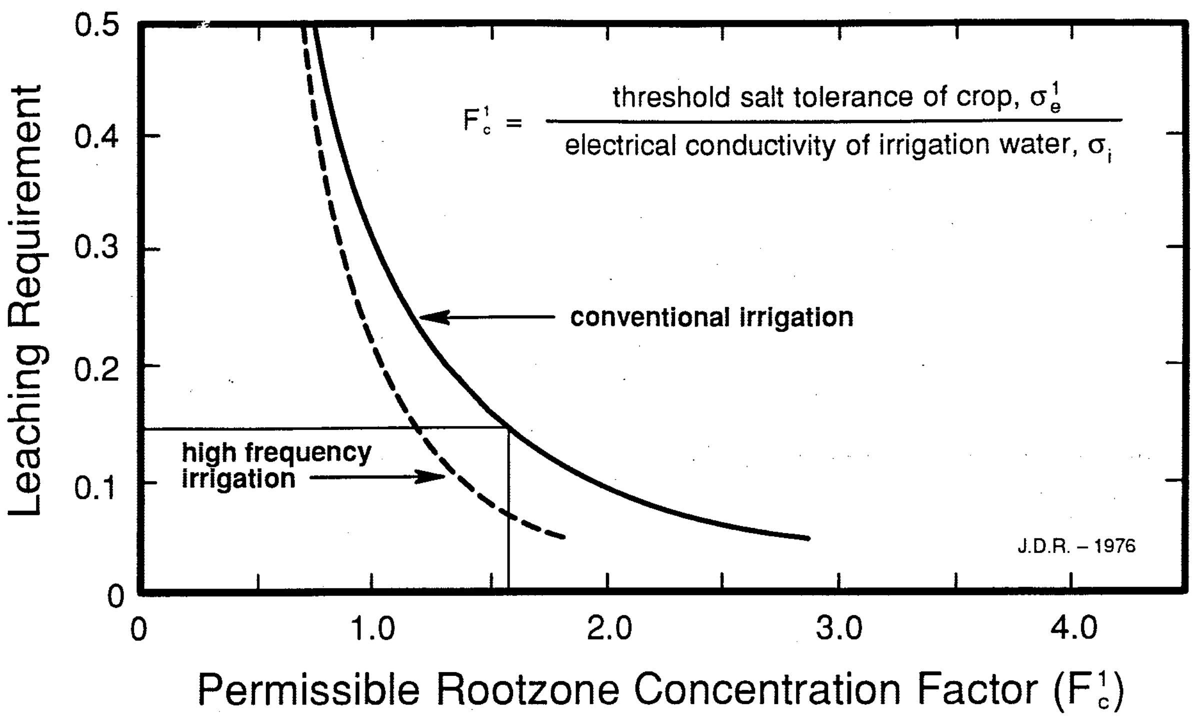
1) Determine the leaching requirement (Lr):

a. Determine the permissible rootzone concentration factor (F'c) by dividing the threshold salinity by the EC_{iw}.

$$F'c = \frac{6}{3.6} = 1.7$$

b. Use the Assessing Leaching Requirement graph to determine the leaching requirement (Lr). Find the value for the permissable rootzone concentration factor (e.g., 1.7) on the horizontal scale. Use a straight edge to draw a line to the appropriate curved line (solid line if using conventional irrigation or broken line if using high frequency irrigation). Then draw a straight horizontal line from that point on the curve to the leaching requirement scale. In this example, the leaching requirement is 0.15.

ASSESSING LEACHING REQUIREMENT



The long-term required leaching is about 0.15. To correct this value for the volume of water that will be used for the season to irrigate (V_{iw}), use this formula:

$$V_{iw} = \frac{V_{cu}}{1 - Lr}$$

Where V_{cu} is the seasonal water requirement (also called the evapotranspiration rate or ET) for the crop.

2) Determine the relative yield (Yr). Assume a leaching fraction of 0.1 (10%). For most soils, except very sandy soils, this is a good assumption.

a. Determine the predicted conductivity of the soil water (EC_e) at equilibrium based on the relative Concentration Factor from the "Leaching Fraction Values for Conventional Irrigation" table. Note: EC_e is on the saturation extract basis.

Assume the suggested leaching requirement of 15% is not possible and the situation allows for a leaching fraction of 10% (0.10).

From the "Leaching Fraction Values for Conventional Irrigation" table, a Leaching Fraction of 0.10 (10%) shows a Concentration Factor of 1.88. Multiply the EC_{iw} by the Concentration Factor to obtain the predicted EC_e.

$EC_e = 3.6 \times 1.88 = 6.8$ mS/cm

This is the predicted salinity of the soil solution.

b. Determine the relative yield (Yr) based on the predicted salinity of the soil solution (ECe).

From the Salt Tolerance of Crops tables (pp.31-36), the threshold salinity of wheat is 6.0 mS/cm. The Slope % is 7.1.

$Yr = 100 - [b(C_e – a)]$ (See page 27 for an explanation of this formula)

$Yr = 100 - [7.1(6.8 – 6.0)] = 94\%$ yield (or a 6% yield reduction)

3) Decide if a crop yield of 94% (6% crop loss) is acceptable. If not, a crop with higher salt tolerance must be grown. If another crop is chosen, the grower should re-evaluate the data for the new crop.

4) Decide if the water will cause permeability problems:

a. Determine the SAR value of the water using the formula or the nomogram for determining SAR on page 25.

For this case, the SAR is 5.1

b. Use this value and the value of the EC_{iw} (3.6 ms/cm for this case) with Permeability Hazard Chart on page 28.

Using these values, the chart indicates that a permeability hazard is not likely.

LEACHING FRACTION TABLE

Leaching Fraction Values for High Frequency Irrigation

Leaching Fraction	Concentration Factor
5%	1.79
10%	1.35
20%	1.03
30%	0.87
40%	0.77
50%	0.70

Leaching Fraction Values for Conventional Irrigation

Leaching Fraction	Concentration Factor
5%	2.79
10%	1.88
20%	1.29
30%	1.03
40%	0.87
50%	0.77

CROP/PLANT TOLERANCE TO IRRIGATION WATER SALINITY

*The following tables are based on papers presented by Dr. Rhoades and E.V. Maas and G.J. Hoffman.***

SALT TOLERANCE OF HERBACEOUS CROPS[a]

Crop		Electrical conductivity of sat'd soil extract		
Common Name	**Botanical Name[b]**	**Threshold[c]**	**Slope**	**Rating[d]**
FIBER, GRAIN AND SPECIAL CROPS				
		dS/m	**% per dS/m**	
Barley	*Hordeum vulgare*	8.0	5.0	T
Bean	*Phaseolus vulgaris*	1.0	19.0	S
Broadbean	*Vicia Faba*	1.6	9.6	MS
Corn	*Zea Mays*	1.7	12	MS
Cotton	*Gossypium hirsutum*	7.7	5.2	T
Cowpea	*Vigna unguiculata*	4.9	12.0	MT
Flax	*Linum usitaissimum*	1.7	12.0	MS
Guar	*Cyamopsis tetragonoloba*	—	—	MT
Millet, foxtail	*Setaria italica*	—	—	MS
Oats	*Avena sativa*	—	—	MT*
Peanut	*Arachis hypogaea*	3.2	29.0	MS
Rice, paddy[f]	*Oryza sativa*	3.0[g]	12.0[g]	S
Rye	*Secale cereale*	—	—	MT*
Safflower	*Carthamus tinctorius*	—	—	MT
Sesame	*Sasamum indicum*	—	—	S
Sorghum	*Sorghum bicolor*	6.8	16	MT
Soybean	*Glycine Max*	5.0	20.0	MT
Sugarbeet[h]	*Beta vulgaris*	7.0	5.9	T
Sugarcane	*Saccharum officinarum*	1.7	5.9	MS
Sunflower	*Heliantus annuus*	—	—	MS*
Triticale	*X. Triticosecale*	—	—	T
Wheat[e]	*Triticum aestivum*	6.0	7.1	MT
Wheat (semidwarf)	*T. aestivum*	8.6	3.0	T
Wheat, Durum	*T. turgidum*	5.9	3.8	T
GRASSES AND FORAGE CROPS				
Alfalfa	*Medicago sativa*	2.0	7.3	MS
Alkaligrass, Nuttall	*Puccinellia airoides*	—	—	T*
Alkali sacaton	*Sporobolus airoides*	—	—	T*
Barley (forage)[e]	*Hordeum vulgare*	6.0	7.1	MT
Bentgrass	*Agrostis stolonifera palustris*	—	—	MS
Bermudagrass[j]	*Cynodon Dactylon*	6.9	6.4	T
Bluestem, Angleton	*Dicanthium aristatum*	—	—	MS*
Brome, mountian	*Bromus marginatus*	—	—	MT*
Brome, smooth	*B. inermis*	—	—	MS
Buffelograss	*Cenchrus ciliaris*	—	—	MS*
Burnet	*Poterium Sanguisorba*	—	—	MS*
Canarygrass, reed	*Phalaris arundinacea*	—	—	MT
Clover, alsike	*Trifolium hybridum*	1.5	12.0	MS
Clover, Berseem	*T. alexandrinum*	1.5	5.7	MS
Clover, Hubam	*Melilotus alba*	—	—	MT*
Clover, ladino	*Trifolium repens*	1.5	12.0	MS

SALT TOLERANCE OF HERBACEOUS CROPS[a] (continued)

Crop		Electrical conductivity of sat'd soil extract		
Common Name	Botanical Name[b]	Threshold[c]	Slope	Rating[d]
		dS/m	% per dS/m	
Clover, red	*T. pratense*	1.5	12.0	MS
Clover, strawberry	*T. fragiferum*	1.5	12.0	MS
Clover, sweet	*Melilotus*	—	—	MT*
Clover, white Dutch	*Trifolium repens*	—	—	MS*
Corn (forage)	*Zea Mays*	1.8	7.4	MS
Cowpea (forage)	*Vigna unguiculata*	2.5	11.0	MS
Dallisgrass	*Paspalum dilatatum*	—	—	MS*
Fescue, tall	*Festuca elatior*	3.9	5.3	MT
Fescue, meadow	*F. pratensis*	—	—	MT*
Foxtail, meadow	*Alopecurus pratensis*	1.5	9.6	MS
Gramma, blue	*Bouteloua gracilis*	—	—	MS*
Hardinggrass	*Phalaris tuberosa*	4.6	7.6	MT
Kallagrass	*Diplachne fusca*	—	—	T*
Lovegrass[k]	*Eragrostis sp.*	2.0	8.4	MS
Milkvetch, Cicer	*Astragalus cicer*	—	—	MS*
Oatgrass, tall	*Arrhenatherum, Danthonia*	—	—	MS*
Oats (forage)	*Avena sativa*	—	—	MS*
Orchardgrass	*Dactylis glomerata*	1.5	6.2	MS
Panicgrass	*Panicum antidotale*	—	—	MT*
Rape	*Brassica napus*	—	—	MT*
Rescuegrass	*Bromus unioloides*	—	—	MT*
Rhodesgrass	*Chloris Gayana*	—	—	MT*
Rye (forage)	*Secale cereale*	—	—	MT*
Ryegrass, Italian	*Lolium italicum multiflorum*	—	—	MT*
Ryegrass, perennial	*L. perenne*	5.6	7.6	MT
Saltgrass, desert	*Distichlis stricta*	—	—	T*
Sesbania[f]	*Sesbania exaltata*	2.3	7.0	MS
Sirato	*Macroptilium atropurpureum*	—	—	MS
Sphaerophysa	*Sphaerophysa salsula*	2.2	7.0	MS
Sudangrass	*Sorghum sudanense*	2.8	4.3	MT
Timothy	*Phleum pratense*	—	—	MS*
Trefoil, big	*Lotus uliginosus*	2.3	19.0	MS
Trefoil, narrow-leaf birdsfoot	*L. corniculatus tenuifolium*	5.0	10.	MT
Trefoil, b.leaf birdsfoot[l]	*L. corniculatus arvenis*	—	—	MT
Vetch, common	*Vicia angustifolia*	3.0	11.0	MS
Wheat (forage)[i]	*Triticum aestivum*	4.5	2.6	MT
Wheat, Durum (forage)	*T. turgidum*	2.1	2.5	MT
Wheatgrass, st. crested	*Agropyron sibiricum*	3.5	4.0	MT
Wheatgrass, frwy.crested	*A. cristatum*	7.5	6.9	T
Wheatgrass, intermediate	*A. intermedium*	—	—	MT*
Wheatgrass, slender	*A. trachycaulum*	—	—	MT
Wheatgrass, tall	*A. elongatum*	7.5	4.2	T
Wheatgrass, western	*A. Smithii*	—	—	MT*
Wildrye, Altai	*Elymus angustus*	—	—	T
Wildrye, beardless	*E. triticoides*	2.7	6.0	MT

SALT TOLERANCE OF HERBACEOUS CROPS[a] (continued)

Crop		Electrical conductivity of sat'd soil extract		
Common Name	Botanical Name[b]	Threshold[c]	Slope	Rating[d]
		dS/m	% per dS/m	
Wildrye, Canadian	*E. canadensis*	—	—	MT*
Wildrye, Russian	*E. junceus*	—	—	T
Vegetable and fruit crops				
Artichoke	*Helianthus tuberosus*	—	—	MT*
Asparagus	*Asparagus officinalis*	4.1	2.0	T
Bean	*Phasoelus vulgaris*	1.0	19.0	S
Beet, red[h]	*Beta vulgaris*	4.0	9.0	MT
Broccoli	*Brassica oleracea botrytis*	2.8	9.2	MS
Brussel sprouts	*B. oleracea gemmifera*	—	—	MS*
Cabbage	*B. oleracea capitata*	1.8	9.7	MS
Carrot	*Daucus carota*	1.0	14.0	S
Cauliflower	*Brassica oleracea botrytis*	—	—	MS*
Celery	*Apium graveolens*	1.8	6.2	MS
Corn, sweet	*Zea Mays*	1.7	12.0	MS
Cucumber	*Cucumis staivus*	2.5	13.0	MS
Eggplant	*Solanum Melongena esculentum*	—	—	MS*
Kale	*Brassica oleracea acephala*	—	—	MS*
Kohlrabi	*B. oleracea gongylode*	—	—	MS*
Lettuce	*Lactuca sativa*	1.3	13.0	M
Muskmelon	*Cucumis Melo*	—	—	MS
Okra	*Abelmoschus esculentus*	—	—	S
Onion	*Allium Cepa*	1.2	16.0	S
Parsnip	*Pastinaca sativa*	—	—	S*
Pea	*Pisum sativum*	—	—	S*
Pepper	*Capsicum annuum*	1.5	14.0	MS
Potato	*Solanum tuberosum*	1.7	12.0	MS
Pumpkin	*Cucurbita Pepo Pepo*	—	—	MS*
Radish	*Raphanus sativus*	1.2	13.0	MS
Spinach	*Spinacia oleracea*	2.0	7.6	MS
Squash, scallop	*Cucurbita Pepo Melopepo*	3.2	16.0	MS
Squash, zucchini	*C. Pepo Melopepo*	4.7	9.4	MT
Strawberry	*Fragaria sp.*	1.0	33.0	S
Sweet potato	*Ipomoea Batatas*	1.5	11.0	MS
Tomato	*Lycopersicon Lycopersicum*	2.5	9.9	MS
Turnip	*Brassica Rapa*	0.9	9.0	MS
Watermelon	*Citrullus lanatus*	—	—	MS*

[a] These data serve only as a guideline to relative tolerances among crops. Absolute tolerances vary, depending on climate, soil conditions, and cultural practices.
[b] Botanical and common names follow the convention of Hortus Third where possible.
[c] In gypsiferous soils, plants will tolerate KeS about 2 dS/M higher than indicated.
[d] Ratings with an * are estimates. For references, see the indexed bibliography by Francois and Maas.
[e] Less tolerant during emergence and seedling stage. Ke at this stage should not exceed 4 or 5 dS/m.
[f] Less tolerant during emergence and seedling stage.
[g] Because paddy rice is grown under flooded conditions, values refer to the electrical conductivity of the soil water while the plants are submerged.
[h] Sensitive during germination. Ke should not exceed 3 dS/m.
[i] Data from one cultivar, "Probred".
[j] Average of several varieties. Suwannee and Costal are about 20% more tolerant and Common and Greenfield are about 20% less tolerant than the average.
[l] Broadleaf birdsfoot trefoil seems less tolerant than narrowleaf.
[**] The reference for the Mass & Hoffman paper is "Crop Salt Tolerance: Evaluation of Existing Data" from proceedings of the International Salinity Conference, Texas Tech University, August 1976. These are in the public domain.

SALT TOLERANCE OF WOODY CROPS[a]

Crop		Electrical conductivity of sat'd soil extract		
Common Name	**Botanical Name[b]**	**Threshold[c]**	**Slope**	**Rating[d]**
		dS/m	**% per dS/m**	
Almond[e]	*Prunus Dulcis*	1.5	19	S
Apple	*Malus sylvestris*	—	—	S
Apricot[e]	*Prunus armeniaca*	1.6	24	S
Avocado	*Persea americana*	—	—	S
Blackberry	*Rubus sp.*	1.5	22	S
Boysenberry	*Rubus ursinus*	1.5	22	S
Castorbean	*Ricinus communis*	—	—	MS*
Cherimoya	*Annona Cherimola*	—	—	S*
Cherry, sweet	*Prunus avium*	—	—	S*
Cherry, sand	*P. Besseyi*	—	—	S*
Currant	*Ribes sp.*	—	—	S*
Date palm	*Phoenix dactylifera*	4.0	3.6	T
Fig	*Ficus carica*	—	—	MT*
Gooseberry	*Ribes sp.*	—	—	S*
Grape[e]	*Vitis sp.*	1.5	9.6	MS
Grapefruit[e]	*Citrus paradisi*	1.8	16	S
Guayule	*Parthenium argentatum*	—	—	T
Jojoba[e]	*Simmondsia chinensis*	—	—	T
Jujube	*Ziziphus Jujuba*	—	—	MT*
Lemon[e]	*Citrus Limon*	—	—	S
Lime	*C. Aurantiifolia*	—	—	S*
Loquat	*Eriobotrya japonica*	—	—	S*
Mango	*Mangifera indica*	—	—	S*
Olive	*Olea europaea*	—	—	MT
Orange	*Citrus sinensis*	1.7	16	S
Papaya[e]	*Carica papaya*	—	—	MT
Passion Fruit	*Passiflora edulis*	—	—	S*
Peach	*Prunus Persica*	1.7	21	S
Pear	*Pyrus communis*	—	—	S*
Persimmon	*Diospyros virginiana*	—	—	S*
Pineapple	*Ananas comosus*	—	—	MT*
Plume; Prune[e]	*Prunus domestica*	1.5	18	S
Pomegranate	*Punica granatum*	—	—	MT*
Pummelo	*Citrus maxima*	—	—	S*
Raspberry	*Rubus idaeus*	—	—	S
Rose apple	*Syzgium jambos*	—	—	S*
Sapote, white	*Casimiroa edulis*	—	—	S*
Tangerine	*Citrus reticulata*	—	—	S*

[a] These data are applicable when rootstocks are used that do not accumulate Na^+ or Cl^- rapidly or when these ions do not predominate in the soil.
[b] Botanical and common names follow the convention of Hortus Third where possible.
[c] In gypsiferous soils, plants will tolerate K_eS about 2 dS/M higher than indicated.
[d] Ratings with an * are estimates. For references, see the indexed bibliography by Francois and Maas.
[e] Tolerance is based on growth rather than yield.

SALT TOLERANCE OF ORNAMENTAL SHRUBS, TREES, AND GROUNDCOVER[a]

Common Name	Botanical Name[b]	Maximum Permissible[b] K_e dS/m
Very sensitive		
Star Jasmine	*Trachelospermum jasminoides*	1-2
Pyrenese cotoneaster	*Cotoneaster congestus*	1-2
Pregon grape	*Mahonia Aquifolium*	1-2
Photonia	*Photonia x Fraseri*	1-2
Sensitive		
Pineapple guava	*Feijoa Sellowiana*	2-3
Chinese holly, cv. Burford	*Ilex cornuta*	2-3
Rose, cv. Grenoble	*Rosa sp.*	2-3
Glossy abelia	*Abelia x grandiflora*	2-3
Southern Yew	*Podocarpus macrophyllus*	2-3
Tulip tree	*Liriodendron Tulipifera*	2-3
Algerian ivy	*Hedera canariensis*	3-4
Japanese pittosporum	*Pittosporum Tobira*	3-4
Heavenly bamboo	*Nandina domestica*	3-4
Chinese hibiscus	*Hibiscus Rosa-sinensis*	3-4
Laurustinus, cv. Robustum	*Viburnum Tin*	3-4
Strawberry tree, cv. Compact	*Arbutus Unedo*	3-4
Crape Myrtle	*Lagerstroemia indica*	3-4
Moderately Sensitive		
Glossy privet	*Ligustrum lucidum*	4-6
Yellow sage	*Lantana Camara*	4-6
Orchid tree	*Bauhinia purpurea*	4-6
Southern Magnolia	*Magnolia grandiflora*	4-6
Japanese boxwood	*Buxus microphylla var. japonica*	4-6
Xylosma	*Xylosma congestum*	4-6
Japanese black pine	*Pinus Thunbergiana*	4-6
Indian Hawthorn	*Raphiolepis indica*	4-6
Dodonaea, cv. atropurpurea	*Dodonaea viscosa*	4-6
Oriental arborvitae	*Platycladus orientalis*	4-6
Thorny elaeagnus	*Elaeagnus pungens*	4-6
Spreading juniper	*Juniperus chinensis*	4-6
Pyracantha, cv. Graberi	*Pyracantha Fortuneana*	4-6
Cherry plum	*Prunus cerasifera*	4-6
Moderately Tolerant		
Weeping bottlebrush	*Callistemon viminalis*	6-8
Oleander	*Nerium oleander*	6-8
European fan palm	*Chamaerops humilis*	6-8
Blue dracaena	*Cordyline indivisa*	6-8
Spindle tree, cv. Grandiflora	*Euonymus japonica*	6-8
Rosemary	*Rosmarinus officinalis*	6-8
Aleppo pine	*Pinus halepensis*	6-8
Sweet gum	*Liquidambar Styraciflua*	6-8

SALT TOLERANCE OF ORNAMENTAL SHRUBS, TREES, AND GROUNDCOVER[a] (continued)

Common Name	Botanical Name[b]	Maximum Permissible[b] K_e dS/m
Tolerant		
Brush cherry	*Syzygium paniculatum*	>8c
Ceniza	*Leucophyllum frutescens*	>8c
Natal plum	*Carissa grandiflora*	>8c
Evergreen pear	*Pyrus Kawakamii*	>8c
Bougainvillea	*Bougainvillea spectabilis*	>8c
Italian stone pine	*Pinus pinea*	>8c
Very Tolerant		
White iceplant	*Delosperma alba*	>10c
Rosea iceplant	*Drosanthemum hispidum*	>10c
Purple iceplant	*Lampranthus productus*	>10c
Croceum iceplant	*Hymencyclus croceus*	>10c

[a] Species listed in order of increasing tolerance based on appearance as well as growth.
[b] Salinities exceeding the maximum permissible K_e may cause leaf burn, leaf loss, and/or excessive stunting.
[c] Maximum permissible K_e is unknown. No injury or growth reduction was apparent at 7 dS/m. The growth of all iceplant species increased by soil salinity of 7 dS/m.

COMMON UNITS OF MEASURE AND THEIR ABBREVIATIONS

UNIT	ABBREVIATION
acre	acre
acre inch	acre-in
bushel	bu
bushel/acre	bu/acre
centimeter	cm
deciSiemen/meter	dS/m
English ton	ton (E)
English ton/acre	Ton (E)/acre
gram	g
hectar	ha
hectoliter	hl
hectoliter/hectare	hl/ha
hundredweight	cwt
hundredweight/acre	cwt/acre
inch	in
kilogram	kg
kilogram/hectare	kg/ha
pounds/acre furrow slice	lbs/AFS
liter	l
meter	m
metric ton	ton (M)
metric ton/hectare	Ton (M)/ha
mhos/meter	mhos/m
micromhos/centimeter	µMhos/cm
microSiemen/centimeter	µS/cm
milligram/liter	mg/L
milliSieman/centimeter	mS/cm
millimhos/centimeter	mMhos/cm
nitrate	NO_3^-
Nitrogen	N
ounce	oz
parts per million	PPM or ppm
phosphate	PO_4^{3-}
phosphorus	P
phosphorus pentoxide	P_2O_5
pound	lb
pound/acre	lb/acre
quart	qt
quintal	q
Siemen/meter	S/m
square foot	ft^2
square kilometer	km^2
square meter	m^2
square mile	$mile^2$
yard	yd

CONVENIENT CONVERSION FACTORS

To convert column 1 to column 2 Multiply by:	Column 1	Column 2	To convert column 2 to column 1 Multiply by
	Length		
1.094	m	yd	0.914
0.394	cm	in.	2.538
	Area		
2.471	ha	acre	0.405
0.386	km^2	$mile^2$	2.591
427.100	km^2	acre	0.00234
	Volume		
0.010	m^3	acre in.	102.8
3.532	hl	ft^3	0.283
2.838	hl	bu.	0.352
0.028	l	bu.	35.21
1.057	l	qt.	0.946
	Mass		
1.102	ton (metric)	ton (English)	0.907
2.205	q (quintals)	cwt.	0.454
2.205	kg	lb.	0.454
453.800	g	lb.	0.002
0.035	g	oz.	28.571
	Yield		
0.446	ton(M)/ha	ton (E)/ha	2.242
0.891	kg/ha	lb/acre	1.122
0.891	a/ha	cwt/acre	1.122
1.150	hl/ha	bu/acre	0.870
	Electrical Conductivity (EC)		
1.000	S/m	Mhos/m	1.0
1.000	dS/m	mMhos/cm	1.0
1.000	mS/cm	mMhos/cm	1.0
1.000	µS/cm	microMhos/cm	1.0
0.001	µS/cm	mS/cm	1000
0.001	µS/cm	dS/m	1000
	Miscellaneous		
1.000	mg/l	ppm	1.0
2.000	ppm	lbs/AFS*	0.5
0.449	kg/ha	ppm	2.227
0.898	kg/ha	lbs/AFS	1.114
0.226	NO_3^-	N	4.431
0.326	PO_4^{3-}	P	3.067
0.437	P_2O_5	P	2.290

•acre furrow slice

GLOSSARY

Absorption—The process of taking in substances (i.e., intake of water by soil, or intake of gases, water, nutrients, or other substances by plants).

Acid—A chemical compound that contributes hydrogen ions (H^+) to an aqueous solution.

Acid Soil*—A soil with a pH value below 7.0. A soil that has a large amount of hydrogen ions (H^+) and aluminum ions compared to hydroxyl ions (OH^-) in the soil solution.

Acre Foot—Equivalent to one foot of water covering one acre (equivalent water volume expressions are 43,560 ft^3, 2.7 million lbs, or 326,700 gallons)

Adsorption—The process by which molecules or ions adhere to a surface (i.e., exchangeable ions on soil particles).

Aerobic (soil)—Soils that contain atmospheric oxygen (O_2) in the pore space.

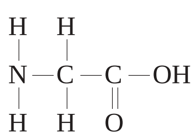
Aggregate*—A group of soil particles cohering so they behave as a unit.

Alkaline (soil)—A soil with a pH greater than 7.0.

Alkalinity—The basic buffering capacity of a soil. The ability of soil to resist the effects of hydrogen ions.

Amendment*—Any material (lime, gypsum) that is added to a soil to improve productivity.

Amino Acids—Amino acids have a chain of carbon molecule for a "backbone", at least one amino group (NH_2) and one carboxyl group (COOH). Some may also contain sulfur. Proteins are made from amino acids.



The amino acid glycine

Ammonification—The biochemical conversion of organic nitrogen to inorganic ammonic form.

Anaerobic (soil)—The absence of molecular oxygen (O_2). This condition exists in soils when they are flooded or compacted.

Anion—A negatively charged ion (i.e., NO_3^-, Cl^-, PO_4^{3-}).

Atmosphere (standard)—The pressure exerted by a column of mercury 760 mm (29.92 in) high. One atmosphere = 14.71 lbs/sq. inch (101,325 Pascals), which is normal pressure at sea level.

Available—The chemical form of a nutrient which can be absorbed and used by plants. This term should not be confused with "exchangeable".

Available Water (soil)*—The fraction of the water in the soil that plants can absorb at rates significant to their growth (also usable or obtainable water).

Base—A chemical compound that contributes hydroxyl ions (OH^-) to an aqueous solution.

Buffered (soil)—A soil that contains enough lime or base saturation to resist change in pH, especially toward acidity. Sandy soils with low cation exchange capacity are low in buffering capacity; clay soils with high cation exchange capacity are highly buffered. Soils that contain excess lime are highly buffered against acidity.

Bulk Density—Also called "apparent density". The mass of dry soil per bulk volume of the soil, including the air space. Bulk density is expressed in lbs/cubic foot or grams/cubic centimeter. When expressed as g/cm^3, bulk density is numerically equal to apparent specific gravity or volume weight. As bulk density increases, the soil porosity (amount of pore space) decreases.

Calcareous (soil)—A soil which is alkaline in pH due to free calcium carbonate. The soil contains enough calcium carbonate to effervesce (fizz) when treated with 10% hydrochloric acid. Normally, these soils have a pH range of 7.5–8.4.

Calcium Sulfate Extractant—Reagent used to extract nitrate from soils. Since nitrates are very soluble in water, the purpose of the calcium sulfate is for easy filtration.

Carbon:Nitrogen Ratio—Compares the amount of carbon in a biochemical system to the amount of nitrogen present. A decomposable material with a wide C:N ratio (> 40:1) would result in soil nitrate being immobilized.

Cation—A positively charged ion (i.e., NH_4^+, Ca^{2+}).

Cation Exchange—The interchange between a positive ion in the soil solution and another positive ion on the surface of a soil particle (e.g., clay or organic matter).

Cation Exchange Capacity—The total quantity of positive ions a soil can absorb, usually expressed as milliequivalents per 100 grams. Measured values of CEC depend on the method of determination. CEC depends on the amount of clay and humus in a soil, the type of clay, and soil pH.

Chelate—Derived from the Greek word "chela", which means claw. Chelates are water-soluble compounds that hold (immobilize) metallic ions. This protects the metal ions from being tied up in the soil in forms that plants cannot use.

Chlorosis*—The deficiency of chlorophyll in a plant. The yellowing of the green portions of a plant, especially the leaves. Chlorophyll gives the plant its green color.

Clay—A soil particle with an average diameter of less than 2 microns (0.002 mm). Soil clays are colloidally active and have a negative surface charge that attracts and holds positive ions.

*Soil Improvement Committee, California Fertilizer Assoc., Western Fertilizer Handbook, 7th ed.

Clay (soil)—A soil texture class that contains less than 40% sand, less than 40 % silt and greater than 40% clay.

Colloid*—Small soil particles with diameters ranging from 0.005-0.200 microns. Colloids in soils (clay and humus) are characterized by high cation exchange due to their large surface area per mass.

Colorimetric Test—A chemical analysis that measures color intensity. The substance being measured reacts with the testing chemical(s) and usually produces a color proportional to its concentration (higher concentration means more color).

Conductivity—The tendency of a medium (soil, water) to transmit electricity. The standard unit of conductivity is the Siemen. Soil solution conductivity is often expressed in milliSiemens/cm. The conductivity of water is often expressed in microSiemens/cm.

Conventional Irrigation—Watering practice which allows the soil to dry out significantly between waterings.

Coring Tube—A metal tube used to obtain soil samples.

DeciSiemens per meter—A unit of conductivity equal to mmhos/cm.

Deionized Water—Water purified with ion exchange resins. Deionized water is often used in chemical analyses.

Denitrification—Process by which nitrate (NO_3^-) is transformed to atmospheric nitrogen (N_2). The N_2 gas is lost from the soil to the air, decreasing the nitrogen in the soil. This process occurs in anaerobic soils.

Dispersed soil—Soil in which the clay easily forms a colloid soil. Dispersed soils usually do not absorb water well. They shrink, crack and become hard when they dry. They slake (run together to form an impermeable film) and become plastic when they are wet. These soils are usually the result of high exchangeable sodium percentage.

Drainage—The discharging of water from soil by surface flow and removal of excess water by downward flow thorough the soil. Includes both natural and artificial water removal.

Dry Weight Basis—a way to express the mineral composition of a plant based on the weight of the plant without moisture. Dry weight is more accurate because the moisture content of plants is variable. If a 100 lbs (45 kg) hay bale contains 8 lbs (3.5 kg) moisture, 92 lbs (41.4 kg) dry matter and 0.3 lbs (0.135 kg) of phosphorus, the concentration of phosphorus on a dry weight basis is 0.3/92 = 0.326% (0.135/41.4 = 0.362%)

Electrical Conductivity (EC)—The reciprocal of electrical resistivity. The ability of a solution to conduct current. In water, EC depends on the concentration of ions (dissolved salts). The term "electrical conductance" is the same as EC.

Equivalent or Equivalent Weight—The weight (grams) of an ion or compound that combines with or replaces 1 gram of hydrogen. The atomic weight or formula weight divided by its valence.

Essential Nutrient (plant)*—A compound is essential to plant if, in its absence, the plant cannot survive. In some cases, the plant can survive if another compound can be substituted for the absent compound.

Evapotranspiration—The loss of water from a soil by evaporation and plant transpiration.

Exchange Complex—The surface-active particles in soils that exchange cations.

Exchangeable Ion*—Ions held in the soil that can be replaced by other ions that have the same charge. Ions which are held so tightly they cannot be exchanged are nonexchangeable.

Exchangeable Sodium—The sodium in a soil held by the negative charges of the soil colloids. As soils increase in exchangeable sodium, they become progressively less permeable to water.

Exchangeable Sodium Percentage—The percentage of sodium that makes up the exchangeable cations in the soil complex.

Extract—The solution that results from combining a soil extractant and the soil.

Extractant—The solvent or chemical used to bring available nutrients into solution out of the soil. Extractants are formulated to dissolve out specific substances, depending on analytical requirements.

Fertility—A measure of a soil's ability to grow a commercial crop.

Fertilizer*—Any natural or manufactured material added to a soil to supply one or more plant nutrients. The term usually refers to inorganic material other than lime or gypsum.

Field Moisture Capacity—The moisture content of soil in the field 2-3 days after a thorough wetting of the soil profile and after free drainage has almost stopped. Field capacity is expressed as moisture percentage, dry-weight basis (how much water per unit weight of soil).

Flocculation—The amount of clay dispersion in a soil. Calcium and magnesium tend to open (flocculate) soils. Sodium tends to close (deflocculate) the soil.

Formula Weight—The sum of the atomic weights of the elements in a compound.

Free Lime Estimation—A simple test using acid to determine if a soil has excess carbonates. The test is positive if effervescence (fizzing) occurs when acid is added to the soil sample.

*Soil Improvement Committee, California Fertilizer Assoc., Western Fertilizer Handbook, 7th ed.

Ground Water—Water in the soil under the soil surface that fills the pores of material underneath the water table. This usually occurs when the pressure holding the water in the soil is greater than the atmospheric pressure and the soil spaces are mostly filled with water.

Gypsum Requirement—The amount of 100% $CaSO_4$ (measured in tons/acre or metric tons/hectare) needed to eliminate the exchangeable sodium in the soil.

Gypsum*—The common name for calcium sulfate ($CaSO_4$), a mineral used as a source of calcium and sulfur. Gypsum is also used in reclaiming sodium affected soils.

High Frequency Irrigation—Watering practice in which the soil does not dry much between waterings. Crops irrigated with this management can tolerate higher salinity irrigation water than crops irrigated with conventional methods.

Humus—The organic matter that remains after initial decay of plant and animal tissues. Most of the soil nitrogen is stored in the humus. As humus slowly decays, nitrogen is released and becomes available to plants. Humus is about 5% nitrogen by weight.

Hydrolysis—The dissolution of a non-neutral salt resulting in a pH change.

Industrial Fixation—Conversion of atmospheric nitrogen to anhydrous ammonia.

Infiltration—The downward flow of water into the soil.

Infiltration Rate—The maximum rate at which a soil can absorb water, under certain circumstances, including an excess of water. It is the volume of water passing into the soil per unit of area over a unit of time.

Ions—Elements that are electrically charged due to loss or gain of an electron. An element that gains an electron becomes negatively charged (anion); an element that loses an electron becomes positively charged.

Leaching—removal of soluble substances by passing water through the soil.

Leaching Fraction—The portion of irrigation water that leaches through the effective root zone.

Leaching Requirement—The fraction of irrigation water that must pass through the root zone to prevent soil salinity from exceeding a specific value. Leaching requirement is usually used under steady-state or long term average conditions.

Lime—Strictly speaking, lime is calcium oxide (CaO), but commonly used in agriculture to mean calcium carbonate ($CaCO_3$) and calcium hydroxide $Ca(OH)_2$.

Lime Requirement—The amount of 100% $CaCO_3$ needed to raise the soil pH to 6.5 or to 7.0 (usually measured as tons/acre or metric tons/hectare).

Loam Soil—A soil textural class that contains moderate amounts of sand (> 52%), silt (28-50%) and clay (7-27%).

Macronutrients*—Nutrients that plants require in large amounts.

Matric Potential—The negative pressure in soil water created by the adsorption of water to the soil particles.

Micronutrients*—Nutrients that plants require in small amounts.

Microsiemens per centimeter (μS/cm)—A measure of conductivity equivalent to 1/1000 milliSiemens per centimeter.

Milliequivalent per Liter (meq/L)—A milliequivalent of an ion or a compound in 1 liter of solution. This unit is often used in irrigation water analysis to quantify the concentration of cations and anions.

Milliequivalent—one thousandth of an equivalent. An equivalent is the amount of a substance equal in reactive power to 1 mole of hydrogen ions.

Milliequivalent Weight—The milligram formula weight of an ion or ionic compound divided by its valence.

Milligram per Liter (mg/l)—A concentration unit expressed as the milligrams of dissolved substance in 1 liter of solution. The unit mg/l is equal to parts per million.

MilliSiemens per Centimeter (mS/cm)—a measure of conductivity equal to 1000 microSiemens per centimeter.

Mineralization—Transforming of a nutrient from organic to inorganic form by microbes in the soil.

Neutral (soil)—Soil with a pH of 7.0. A soil that is neither acid or alkaline.

Nitrification—Aerobic microbial conversion of ammonium nitrogen to nitrite and then to nitrate.

Nitrogen Fixation—Conversion of nitrogen gas to a form that is available to plants.

Nitrogen Requirement—The actual amount of nitrogen needed by a plant for desired growth. Determined by multiplying the yield goal (bushels/acre or hl/ha) by the amount of nitrogen required to produce one bushel. Nitrogen requirement is not the same as nitrogen fertilizer recommendation. The fertilizer recommendation is determined by taking the difference of the nitrogen requirement minus the soil nitrogen sources (manure, residual nitrate, etc.).

Non-symbiotic Fixation—Conversion of atmospheric nitrogen to protein by soil microbes.

*Soil Improvement Committee, California Fertilizer Assoc., Western Fertilizer Handbook, 7th ed.

Organic Matter—The solid fraction of the soil that is non-mineral. This includes the living organisms, fresh tissue, and humus.

Osmotic Pressure—The tendency of a fluid to pass through a semipermeable membrane into a solution which has a higher concentration of solids or ions, making the concentration of the solids or ions equal on both sides of the membrane.

Particle Density—The average density of the soil particles, usually expressed in grams/cubic centimeter. It is also called "real density" or "grain density". The average particle density of most mineral soils is 2.65 g/cm^3.

Parts per Million—Unit of measure used to express the available nutrient concentration in soil. One ppm is equivalent to 2 lbs/acre (2.2 kg/ha) if the soil sample is taken at the depth of the plow layer. ppm is chemically equivalent to mg/L.

Percent Base Saturation—The percentage of the cation exchange capacity that is due to base cations (calcium, magnesium, sodium, and potassium).

Percolation—The downward movement of water through soil, especially in saturated or nearly saturated soil. This is a qualitative term.

Permanent Wilting Percentage—The moisture percentage at which plants wilt and cannot recover tissue rigidity. Significant for non-saline soils only since salinity can cause permanent wilting at higher moisture percentages than the permanent wilting percentage.

Permeability—1) Qualitative–How well a porous medium will conduct, absorb, or transmit a fluid. 2) Quantitative–The property that controls the rate with which a porous medium transmits fluids under standard conditions.

pH—A numerical expression of the acidity, neutrality, or alkalinity of a system. The pH of soils is often called the "soil reaction".

Photosynthesis*—The process in green plants that combines water and carbon dioxide to form carbohydrates which requires energy from light (sun). Chlorophyll is required to convert the light energy into chemical energy.

Plant Nutrition—The biochemical process of absorption, assimilation, and utilization of essential compounds for plant growth and reproduction.

Porosity—The fraction of soil volume that is not occupied by soil particles. It is the volumes of the liquids and gases compared to the volumes of the solids, liquids, and gases of the soil.

Profile—A vertical cross-section of a soil. Often the various horizons (topsoil, subsoil, parent material) can be seen and classified in the profile.

Reclamation—The removal of excess soluble salts or exchangeable sodium from soils.

Residual Nitrate—The nitrate-nitrogen remaining in the soil after harvest.

Saline (soil)—A nonsodic soil that contains soluble salts in quantities that interfere with the growth of most crops.

Saline-Sodic (soil)—A soil that contains enough exchangeable sodium to interfere with the growth of most crops and also contains large amounts of soluble salts.

Salinity—The amount of dissolved salts in a medium (as in "the salinity of the soil").

Salinization—The accumulation of soluble salts in soil.

Salt Affected Soil—A soil that contains enough soluble salts, and/or exchangeable sodium to interfere with normal plant growth. Salt affected soils are usually categorized into three groups: 1) saline, 2) sodic, and 3) saline-sodic.

Sand—A soil mineral particle that is between 0.05 and 2.0 mm in diameter.

Sand (soil)*—The textural name of any soil that contains 85% or more sand and not more than 10% clay.

Saturated Soil Paste—A mixture of soil and water. At saturation, the soil paste will glisten, flow slightly when the container is tipped, and the paste will slide freely and cleanly from a spatula (except soils with a high clay content).

Saturation Extract—The solution extracted from a soil at its saturation percentage.

Saturation Percentage—The moisture percentage of a soil paste, expressed on a dry-basis weight. For example, if 100 grams of soil contains 36 grams of water at saturation, the saturation percentage is 36%.

Separate (soil)—One of the three sized mineral particles that make up soil texture. The soil separates are sand, silt, and clay.

Silt—A soil mineral particle between 0.002 and 0.05 mm in diameter.

Silt (soil)—Soil textural class contain 80% or more silt and less than 12% clay.

Sodic Soil—A nonsaline soil containing enough exchangeable sodium to interfere with growing most crops.

Sodicity—The level of exchangeable sodium and its influence on a soil.

Sodium Adsorption Ratio—A ratio that expresses the relative activity of sodium ions in exchange reactions with soil. Used for both soil and irrigation water.

*Soil Improvement Committee, California Fertilizer Assoc. Western Fertilizer Handbook, 7th ed.

Sodium Estimation—In irrigation water, the estimation of sodium is calculated from known conductivity and calcium and magnesium values using this formula:

Est. Sodium meq/L = EC_{iw} mS/cm x 10 – (Ca + Mg meq/L)

Soil Moisture Stress—The sum of the soil-moisture tension and the osmotic pressure of the soil solution.

Soil Moisture Tension— The equivalent negative pressure or suction of water in soil. Tension and suction are negative potentials, which means they reduce the free flow of water in the soil.

Soil Solution—Water in the soil that contains dissolved salts and nutrients.

Standard—A solution of known concentration used to calibrate or prove an analytical procedure is accurate and valid.

Structure (soil)*—The physical arrangement of the soil particles. Soil structure is important for adequate root growth and water percolation.

Subsoil*—Generally, that part of the soil below the plow depth. Subsoil is usually lower in organic matter and has less oxygen than topsoil.

Symbiosis*—The living together of two different organisms that may result in mutual benefit.

Symbiotic Fixation—Conversion of atmospheric nitrogen to protein by heterotrophic bacteria living in association with a host legume.

Texture (soil)*—The relative proportions of the various size groups of individual soil grains (separates) in a soil. Specifically, it refers to the proportions of sand, silt, and clay.

Threshold Salt Tolerance (crop)—The conductivity of the saturated paste extract at which a plant experiences reduction in growth.

Tilth*—The physical condition of a soil which allows the growth of plants.

Titrant—A standard solution of known concentration and composition used in a titration to bring about the endpoint. In the Ca+Mg (hardness) test, the titrant is the chelate EDTA.

Titration—A method for analyzing the composition of a solution by adding a known amount of standardized solution (titrant) until a reaction (color change, precipitation, conductivity change) occurs. The volume of solution added indicates the concentration of the substance being analyzed.

Topsoil—The upper horizon of a soil profile that is usually the plowed layer in soils that are farmed. Topsoils are more aerated and higher in organic matter than the soil layers below it.

Total Exchangeable Acidity—The amount of exchangeable H^+ and Al^{3+} in a soil.

Transpiration*—The loss of water vapor from the leaves and stems of living plants into the air.

Volatilization—Relative to soil nitrogen, the loss of nitrogen as a gas from the soil.

Water Table—The upper boundary of groundwater.

*Soil Improvement Committee, California Fertilizer Assoc., Western Fertilizer Handbook, 7th ed.

BIBLIOGRAPHY

Western Fertilizer Handbook, 7th edition
Soil Improvement Committee, California Fertilizer Association
The Interstate Printers and Publishers, Inc.
Danville, Illinois
ISBN 0-8134-2409-9

Maas, E.V.
"Salt Tolerance of Plants" (Abstract)
Applied Agricultural Research Vol. 1, No. 1, pp. 12-26.
1986
Springer-Verlag, New York, Inc.

United States Salinity Laboratory Staff
"Diagnosis and Improvement of Saline and Alkali Soils"
U.S. Department of Agriculture Handbook 60
U.S. Government Printing Office
Washington, D.C. 1954
out of print

Rhoades, J.D.
"Evidence of the Potential to Use Saline Water for Irrigation"
Proceedings from the International Seminar on the Re-use of Low Quality Water for Irrigation
Egypt, January 1988

Rhoades, J.D.
"Using Saline Waters for Irrigation"
International Workshop on Salt-Affected Soils of Latin America
International Society of Soil Science
Maracay, Venezuela 1983

Recommended Chemical Soil Test Procedures (North Central Region)
North Central Regional Publication No. 221 (revised)
October 1988
North Dakota Agricultural Experiment Station
North Dakota State University
Fargo, North Dakota 58105

Handbook on Reference Methods for Soil Testing (revised edition)
The Council on Soil Testing and Plant Analysis
1111 Plant Science Building
University of Georgia
Athens, Georgia 30602