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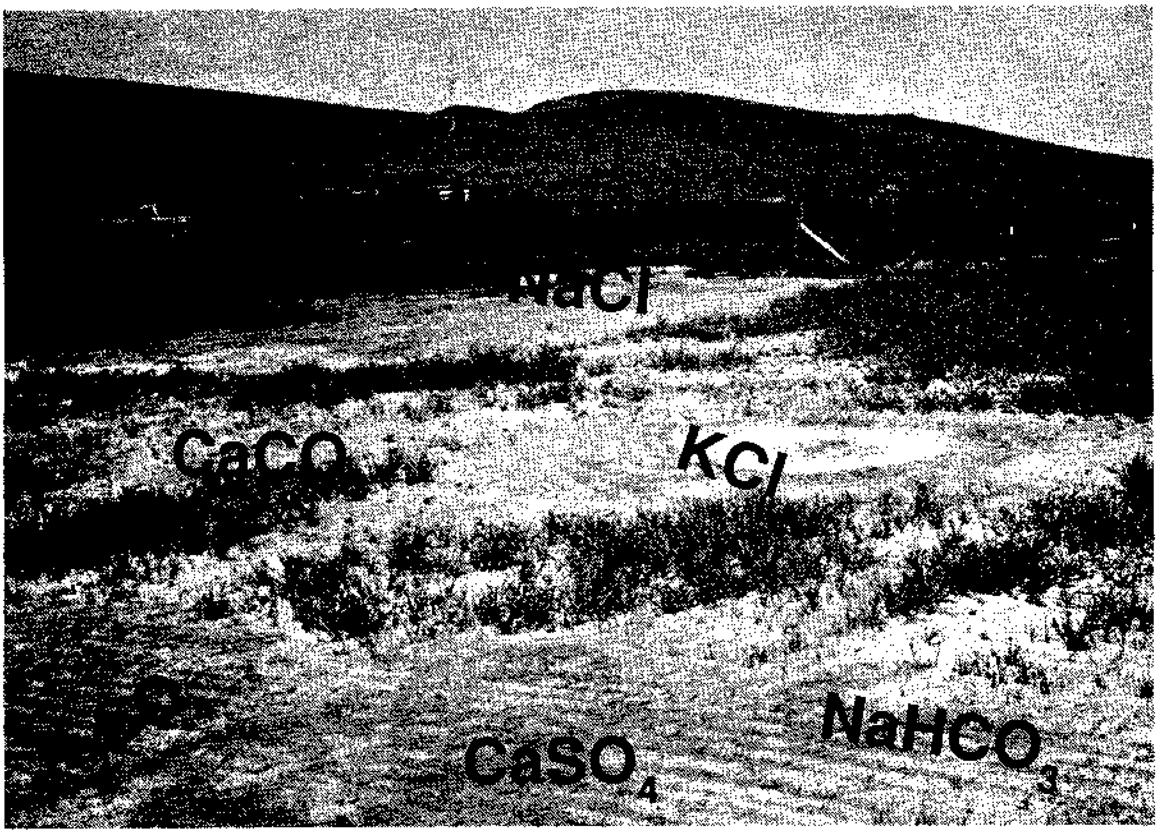
Salt- and Sodium-affected Soils



Charles W. Robbins and Raymond G. Gavlak

Research Education Extension
College of Agriculture

Cooperative Extension Service
University of Idaho
College of Agriculture

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*Charles W. Robbins and Raymond G. Gavlak**

This publication is designed to help identify salt- and sodium-affected soils, the salt or sodium sources, how to take soil and water samples, how to reduce the harmful effects of salts and sodium and where to get advice in making reclamation and management decisions for each situation.

Salt- and sodium-affected soils, and waters used for irrigation, present a complex combination of problems and possible solutions. It is not the intent here to cover all technical aspects or possible treatment approaches available, but rather to give a simplified overview of what should be considered in diagnosing and managing salt- and sodium-affected soils and irrigation waters. Since summarizing the effects of salt and sodium on soils and plants is difficult without using the appropriate terminology, a glossary is included.

Salts and Ions

When an acid and a base are mixed, a salt is formed. For example, if lye, which is sodium hydroxide, is neutralized with hydrochloric acid (muriatic acid used for soldering), common tablesalt (sodium chloride) and water are produced. Neutralizing sulfuric acid (battery acid) with quicklime (used to make brick mortar) produces gypsum, a slightly soluble salt, and water. Sodium and calcium chloride salts are very soluble; salts like gypsum are only slightly soluble, and salts like calcium carbonate (lime) are only very slightly soluble.

When a salt dissolves in water, it dissociates or separates into cations and anions. Cations carry a positive electrical charge and anions carry a negative electrical charge. The cations of most concern in salt-affected soils are calcium, magnesium, sodium and occasionally potassium. The anions of concern are chloride, sulfate, carbonate and bicarbonate. In a few areas, boron or borate ion damage to plants is a problem associated with salt-affected soils. Boron should be considered a toxic ion, rather than a salt, because boron inhibits plant growth at a much lower concentration than the other ions.

In addition to soluble cations, another category of cations are of concern in soils. These are the exchangeable cations. Clays and organic matter carry a negative electrical charge. This negative charge must be satisfied by an equal quantity of positive electrical charge. In salt-affected soils, this charge is satisfied by calcium, magnesium, sodium and potassium cations. The cations are very tightly held by the negative electrical charges. These are referred to as exchangeable cations because they can only be removed from the negatively charged surface by replacement with another cation from the soil solution.

Salt and Ion Effects On Plants and Soils

Osmotic Potentials develop when any salt or sugar dissolves in water. This can be illustrated by visualizing a tank with a semi-permeable membrane divider. Water can pass through the divider or membrane, but salt cannot. If the tank is partially filled with water until both compartments have equal water levels and salt is added to one compartment, water will move through the membrane from the pure water side into the salty water side until the difference in the two water levels is equal to the difference in the osmotic potential. The greater the difference in the salt concentrations across the membrane, the greater the difference in energy or osmotic potential.

Plant roots contain sugar and salts. When plants grow in damp, non-salty soil, water readily moves from the soil into the plant due to the difference in osmotic potential between the soil water and the root sap. As the soil dries, the remaining water is more tightly held to the soil particle surfaces and the salt concentration in the soil solution increases. These changes cause the water flow rate into the plant to decrease as the soil water potential increases. If water is not added to the soil, a point in the drying process is reached where the roots can no longer take up enough water to meet the plant needs. Plant growth stops and the plant eventually dies. The less dissolved salt there is in the soil solution, the lower the plant can reduce soil water content without affecting plant growth. The higher the salt concentration, the less available the soil water is to the plant. All soluble salts contribute to the osmotic effect.

***The Authors** — Charles W. Robbins is a Soil Scientist, Soil and Water Management Research Unit, USDA-Agricultural Research Service, 3793 N. 3600 E., Kimberly, ID 83341. Raymond G. Gavlak, formerly an Extension Soil Scientist with the University of Idaho Cooperative Extension Service, is presently Extension Agronomist, University of Alaska, Palmer, Alaska.

Specific Ion Effect is the adverse effect on plant growth that is peculiar to each ion, in addition to its osmotic effect. The specific ion effect of some ions is quite prevalent, while specific ion effect is rarely found for other ions. Some plants are very sensitive to chloride and sodium ions and show signs of leaf margin or tip burn, leaf bronzing or necrotic spots. Other plants are quite tolerant to these ions. High carbonate and bicarbonate ion concentrations in the soil solution inhibit iron uptake by many plants. The shortage of iron causes the plants to be pale green to yellow. This is often referred to as lime-induced chlorosis. High potassium concentration in the soil can inhibit some crops, especially grasses, from taking up normal amounts of magnesium. Boron concentrations above 2 ppm in the soil solution are toxic to most crops. Salt injury also is related to soil nitrate levels. Many crops are more sensitive to high salt concentrations when the soil nitrates are below levels for optimum plant growth. Under certain conditions, higher than normal nitrate applications will partially offset salinity-induced yield reductions.

Soil Physical Properties are adversely affected when the predominant cation in the soil is sodium. In some cases, magnesium can also adversely affect physical soil properties. If the sodium adsorption ratio (SAR) is greater than 13 or the exchangeable sodium percentage (ESP) is greater than 15, the soil may become "dispersed." Dispersed soils have reduced capacity for intake and movement of water. Dispersion problems are greatest if the soluble salts are low (EC less than 4 mmhos/cm). (Dispersion, SAR, ESP and EC are explained in the glossary.) The dispersed soil particles may seal-over the soil surface and develop restrictive layers within the soil profile. These conditions impede air movement and water infiltration into and through the soil.

One of the most serious problems in reclaiming sodic soils (high SAR and ESP and low EC) is getting water to move through the soil to remove undesirable salts and replace exchangeable sodium with calcium (Fig. 1). Calcium is the most desirable ion to have as the dominant soluble and exchangeable cation. Ideally, calcium should make up 60 to 80 percent of the exchangeable cations.

An old saying is appropriate to remember: "Hard water makes soft soils and soft water makes hard soils." This says that irrigation waters containing predominantly calcium and magnesium salts (low SAR) tend to promote more friable soil conditions. Irrigation waters with low calcium and high sodium ratios (high SAR) tend to cause soils to disperse, form crusts, become compacted and have very low infiltration rates and poor air movement properties.

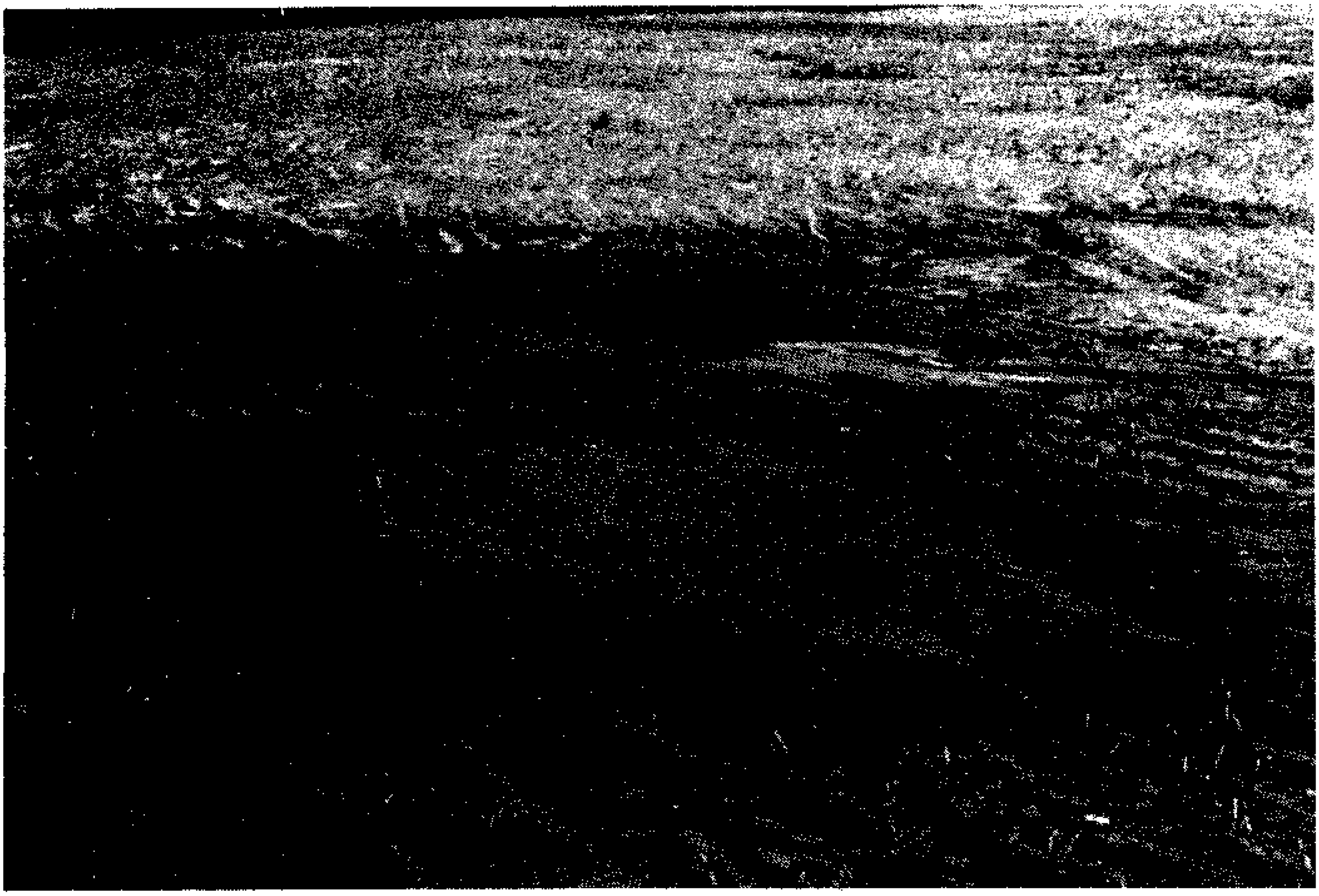

Fig. 1. Poor water infiltration occurs on sandy loam soil because of dispersion under sodic conditions. In this location, standing water remained 7 days after a rain shower.

Soil Salt Sources

Soluble salts and exchangeable cations in salt-affected soils come from several sources. Recognizing the source is the first step in deciding what can be done to remove or minimize their adverse effects. The origin of these salts and cations usually determines whether it is economical to reclaim the soils.

Most soluble salts and exchangeable cations in soils come from weathering of rocks and minerals that served as the soil parent materials. Natural weathering processes such as stream bed grinding, dissolution by water and acids from rain water and plant roots, oxidation by air and water and alternating freezing and thawing bring ions into solution. In high rainfall, humid and tropical areas, rain water leaches the salts from the soil as they form. In arid and semi-arid areas, the potential annual evapotranspiration is greater than total annual precipitation, and the salts are not always leached from the soil as fast as they are released. With time, they accumulate in the root zone at concentration levels that affect plant growth.

Salts often accumulate in soils above shallow water tables. The water table may be naturally occurring or may have been induced by irrigation project development in poorly drained areas, by irrigating lands upslope from the salt-affected areas or by construction that blocked natural subsurface lateral drainage. Water moves from the water table to the soil surface by capillary rise or "wicking" and evaporates from the soil surface, leaving the salts on or near the surface. Over time, the salts become sufficiently concentrated to inhibit plant growth. This kind of salt problem is usually found in low lying, flat areas and along slow moving streams, drains and marshes.

All irrigation waters contain at least some dissolved salts. In many areas, good quality (low salt and low sodium) water is not available for irrigation; consequently, water containing higher than desirable levels of salt or sodium is often used. When this water is used and too little water moves through the soil to carry the salts below the root zone, salts or sodium will accumulate in or near the soil surface.

The salts added by fertilizers are usually not a concern. If the fertilizer or manure is uniformly spread over the soil, the salinity effect is usually not measurable. Very soluble fertilizers, such as muriate of potash or ammonium nitrate, applied uniformly at 300 pounds per acre, will initially raise the EC by about 0.3 mmhos/cm. This would be of short duration and would have very little effect on most crops. Irrigation or precipitation will quickly dilute the added salt. When these fertilizers are banded near seeds or small plants, however, the salinity effect can be severe. The less soluble fertilizers such as phosphates would have much less effect.

The ammonium ion from nitrogen fertilizer or manure, on the other hand, can be toxic to germinating seeds and seedlings, a problem that may be confused with salt affect. Most manure application rates will not produce measurable salt effects, though some feedlot manures may contain high salt (sodium chloride) concentrations. If sufficiently heavy amounts of high sodium chloride manure are applied to a slightly sodic soil, infiltration rates may be reduced.

Salt spills or intentional dumping of salt solutions from oil well mud ponds, mines, food processing plants, municipal sewage water or power plant cooling tower water, or heavy wood ash applications and other industrial activities often cause salt or sodium problems. Soil reclamation is very difficult when the salts are added in high concentration to normally low salt soils, especially in the higher rainfall areas.

Saline and Sodic Soil Categories

Arid and semiarid soils can be grouped into categories of normal, saline, sodic and saline-sodic soils. These are the currently acceptable names for identifying these soils. A mix of two or more kinds of salt-affected soil within a single field is not uncommon. Severity of salt-affected soil is usually highly variable from one part of a field to another.

Normal Soils do not contain sufficient soluble salts to reduce crop yield nor do they contain sufficient exchangeable sodium to impede water movement into or through the soil. The upper limit of electrical conductivity in the saturation paste extract (EC) of these soils is 4 mmhos/cm, and the exchangeable sodium percentage (ESP) upper limit is 15. These are defined upper limits. If salt-sensitive crops such as beans, apples, pears, many ornamentals, small fruits and berries were grown on soils with an EC of 3.5 mmhos/cm, a significant yield reduction would be expected. Likewise, irrigating most soils with water having an ESP of 12 with a high volume sprinkler system would produce serious runoff problems caused by the adverse sodium effect on soil structure (dispersion). A normal soil then is one where soluble salts or high exchangeable sodium do not adversely affect yield or quality of the more salt-tolerant crops.

Saline Soils contain sufficient soluble salts (EC greater than 4 mmhos/cm) in the upper root zone to reduce yields of most cultivated crops and ornamental plants. Sodium makes up less than 15 percent of the exchangeable cations (ESP less than 15), and the pH is usually less than 8.3. Water entry and movement through these soils is not inhibited by sodium-induced dispersion. In the past these soils have been called white alkali or salty soils.[1] The predominant cations are calcium, magnesium and, in a few cases, potassium. The predominant

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[1] Terms such as alkali, white alkali, black alkali and salty are often used to describe these soils. These terms do not mean the same thing to all people, thus causing considerable confusion in describing the problems associated with these soils.

anions are chloride and sulfate. Bicarbonate may be present to a lesser extent in high magnesium or potassium soils. Osmotic effects and chloride toxicity are the predominant causes of yield reduction and plant injury.

Saline-Sodic Soils are similar to saline soils in that the EC is also greater than 4 mmhos/cm, and the pH is usually below 8.3. Saline-sodic soils differ from saline soils in that more than 15 percent of the exchangeable cations are sodium and the saturation paste SAR is greater than 13. The anions are predominantly chloride and sulfate with some bicarbonate when the pH is greater than about 7.5. The pH of a 1-to-5 soil:water suspension is usually at least 1 pH unit greater than the saturation paste pH. As long as the EC remains above 4 mmhos/cm, infiltration rate and hydraulic conductivity are generally as high as in normal or saline soils. On low gypsum or gypsum-free soils, leaching with good quality, low calcium irrigation water will change these soils to sodic soils as the EC decreases without a decrease in ESP. When this happens, the undesirable properties of sodic soils will be expressed in crop growth (Fig. 2). Saline-sodic soils have been called white alkali in the past.[1] High osmotic and specific ion effects are the predominant cause of plant growth reduction.

Sodic Soils are lower in soluble salts than saline-sodic or saline soils. The EC is less than 4 and often less than 2 mmhos/cm. The saturation paste pH is usually greater than 8.5 and can be higher than 10 in extreme cases. Higher carbonate and hydroxide ion concentrations exist in these soils than in other soils. This causes the calcium to precipitate out of solution as $CaCO_3$ or lime. The ESP is greater than 15 and saturation paste extract SAR is greater than 13. The combination of high ESP, high pH and low EC causes the soil to disperse. This dispersion of soil particles destroys the soil structure and causes the soils to "puddle" or "run together," forming the characteristic "slick spots." These spots have extremely low water intake rates. The soil often has a black, greasy- or oily-looking surface with little or no vegetative growth (Fig. 1). In the past, these soils have been called black alkali.[1]

The four categories of saline- and sodium-affected soils are summarized in Table 1.

Table 1. Chemical parameters defining salt- and sodium-affected soils.

Salinity class	EC	ESP	SAR	pH
Normal soil	<4.0	<15	<13	<8.3
Saline soil	>4.0	<15	<13	<8.3
Saline-sodic soil	>4.0	>15	>13	<8.3
Sodic soil	<4.0	>15	>13	>8.5

Fig. 2. Lack of crop and poor crop growth results from saline-sodic soils being irrigated with high quality water.

Irrigation Water Classification

Irrigation water quality is based on three criteria: total salt concentration (EC_{iw}), sodium adsorption ratio (SAR) and adjusted sodium adsorption ratio (SAR_{adj}).

Low Salinity Irrigation Water has an EC_{iw} between 0 and 0.4 mmhos/cm (0 to 250 ppm). All crops can be grown with this salt concentration in the water as long as periodic leaching takes place. On moderately to well-drained soils, salts in the soil will not increase and may even decrease with time under these conditions.

Moderately Saline Irrigation Water has an EC_{iw} between 0.4 and 1.2 mmhos/cm (250 to 750 ppm). Very salt-sensitive crops require specialized practices to avoid salt injury. Moderately tolerant crops can be grown if sufficient leaching is allowed to prevent salt buildup in the root zone.

Highly Saline Irrigation Water has an EC_{iw} between 1.2 and 2.3 mmhos/cm (750 to 1,500 ppm). This water should only be used on well-drained soils with high infiltration rates and no shallow water table. Only salt-tolerant crops can be successfully grown. Sprinkler irrigation during hot weather is not advisable. Excess water must be applied to leach salt from the root zone. Degradation of underlying aquifers may be a concern.

Very Highly Saline Water has an EC_{iw} of 2.3 to 5.0 mmhos/cm (1,500 to 3,200 ppm). Water in this salinity range is acceptable only for extremely porous, well-drained soils and very salt-tolerant crops. A lower salinity water may be needed for seedling germination and crop establishment. Degradation of subsurface water supplies is likely under lands irrigated with this quality of water.

Brackish Water has an EC_{iw} in excess of 5.0 mmhos/cm (3,200 ppm) and should not be considered for irrigation under any conditions.

The SAR of an irrigation water should be considered along with the EC_{iw} in determining the ultimate suitability of a water for irrigation. The higher the SAR, the greater the probability that infiltration rates and water flow through the soil will become a problem. Adjusted SAR or SAR_{adj} is a value for SAR that has been corrected for bicarbonate and carbonate concentrations in the irrigation water. This correction is discussed later.

Collecting Samples

Soil Samples

Soil sample collection should be based on visual observations in the field. Visual observations can include differences in soils, landscape form, past management and severity of salinity and sodium. If the land has not been recently farmed or is in native vegetation, the vegetation can give an indication of where the saline- or sodium-affected areas are located. Saline and sodic soil indicator plants in the moderate and cool temperature areas include salt grass (*Distichlis stricta*), kochia weed (*Kochia*), greasewood (*Sarcobatus vermiculatus*) and tamarack (*Larix*). These grow on very salty or high pH soils. Tall sweetclover (*Melilotus* spp.), rabbit brush (*Chrysothamnus nutt*) and tall wheat grass (*Agropyron elongatum*) will grow on moderately saline areas. Big sagebrush (*Artemisia tridentata*) and the high quality native grasses will only grow on soils that are not salt-affected. In hotter climates, other plants such as desert saltbrush (*Atriplex polycarpa*) and cressa (*Cressa truxillensis*) can be used as saline soil indicator plants.

Crop height and color can help identify saline- or sodium-affected areas in cultivated fields. Some crops are more salt- or sodium-tolerant than others, and the degree of injury will vary with crop and management practices. Crops such as beans or potatoes will show greater salt injury than peas, onions, corn or wheat. Barley, alfalfa, sugarbeets and yellow sweet clover show the least salt damage. In very severe cases, when the predominant anions are chloride, saline areas may appear as white crusts or as white or tan areas with a floury, dusty surface when dry. Furrow-irrigated areas may have white or salty strips along the furrow edge or between the furrows. High pH, sodic areas will appear as black, oily-looking spots when dry and as shiny ''slick spots'' when wet. These slick spots will have very low water infiltration rates. If they are in low or flat areas, water will stand for extended periods without soaking into the soil (Fig. 1).

Once the plant responses, water infiltration rates and soil and landscape differences have been identified, the field should be divided into sections for sampling. The divisions should be selected to provide the most information about the field within the limits of the number of samples to be taken. This may be a time when outside help would be advisable — keeping in mind who is going to pay the analytical bills.

One or more samples should be taken from the most productive parts of each field. Several samples should also be taken from the least productive parts and from the areas of intermediate productivity. This will give a measure of the overall degree of salinity or sodium problems.

Each soil sample should be a composite of several subsamples that are taken from different locations in what appears to be a relatively uniform area of the field. If the composite sample is too large, it can be divided. It must, however, be thoroughly mixed, with all soil clods or lumps thoroughly crushed, before the portion is taken to be sent for analysis.

Sampling depth and number of depths to be taken presents an additional choice. Here again cost becomes a factor. If one depth is used, the sample should probably be from the surface down to 9 or 12 inches. If two sample depths are used, the upper sample should probably be from the surface down to 6 or 8 inches and the second should be from 6 to 12 or 8 to 16 inches, depending on soil condition. Sampling by soil horizons is most desirable, for example, sampling from the surface down to bottom of the plow layer, and from the bottom of plow layer down to the bottom of the next horizon. Occasionally, a 1- or 2-inch deep sample of a soil crust or salt layer may be desirable.

One quart (2 pounds) of soil is usually adequate for each soil sample (Fig. 3). Each sample should be identified by sampling date, depth, relative crop growth and appearance, previous and current or next crop and location by field and within the field. Descriptions of soil color, salt crusts, moisture content, water table, hard pans or claypans and topography are also useful information.

Samples should be air-dried (do not dry in an oven) and thoroughly mixed. Sticks and stones larger than ½ inch should be removed. The samples should be placed in a clean, durable, airtight container that is easily handled, and then stored in a dry, cool area until they are delivered to the testing laboratory.

Water Samples

Water samples from wells should be taken only after the pumps have run for at least an hour, so that water standing in the well casing and the area next to the well is removed and a representative sample is obtained. Usually, well water quality will not change during the growing season. In a few cases where an aquifer is being lowered by pumping, the water quality may change with time. In these cases, sampling the wells throughout the irrigation season might be wise.

Irrigation water quality in large river systems with large storage reservoirs will usually not change over the season, but water in small storage systems and stream systems with fluctuating flows may change as the flow changes. Water samples should be taken only during the irrigation season and should also be taken as the water flow changes. Once the well or stream water quality has been established, sampling every year will probably not be necessary.

Fig. 3. One quart soil samples are collected for laboratory analysis from areas with poor crop response.

One cup (8 ounce) water samples are sufficient for most irrigation water quality analyses. Sample containers should be clean and free from oil, salts or chemical contaminants. Rinse each container with the water to be sampled before saving the sample. Use tight closures and record the sample date, time, place, water flow (approximate), irrigation method and crops to be grown. Refrigerate (do not freeze) the samples until analyzed and analyze as soon as practical. Indicate which water samples go with which soil sample when more than one water source is available. Water quality data and soil salinity and sodium status are needed together to make proper management decisions.

When a high water table is suspect, make bore holes down into the water table near each corner of the field. Water samples should be taken from each hole, and the depth below the soil surface to the water surface should be measured once the water has stopped rising in each hole. These sampling procedures should be carried out at the beginning and end of the irrigation season. This will give an indication of irrigation and seasonal effects on the water table depth and quality. These water samples should be analyzed by the same procedures as the irrigation water samples.

Soil and Water Analyses

Once the samples are collected and labeled, take them to a private soil testing laboratory, or to a university soil testing laboratory. Samples to be tested for salinity and sodium are handled differently than samples collected for fertilizer analysis and recommendations. When salinity or high sodium is a concern, the following tests are requested:

1. Saturation paste (not extract) pH. If sodium seems to be a problem, a 1:5 soil:water pH should also be run.
2. Saturation paste extract should be analyzed for Ca, Mg, Na and electrical conductivity (EC). Potassium should be requested in some locations. Some laboratories would rather use a 1:1 or 1:5 soil:water extract than a saturation paste extract. **Ask specifically for saturation paste extract data.** The 1:1 and 1:5 extracts cannot be interpreted in relation to standard salinity and sodium guidelines.
3. Carbonate, bicarbonate, chloride and sulfate should be run on enough saturation paste extracts to get an idea of which anions are dominant.
4. If pH is greater than 8.5 and EC less than 4.0 mmhos/cm, or if SAR is greater than 10, exchangeable sodium percentage (ESP) should be run. The cation exchange capacity (CEC) should not be run on more than four samples per field. Soil CEC does not change appreciably across a field unless soil texture, organic matter or other major soil characteristics change.

5. Irrigation water analyses should include EC_{iw}, calcium, magnesium, sodium, chloride, carbonate, bicarbonate, sulfate and occasionally potassium. In areas of known boron toxicity, boron also should be determined.

Be sure that your samples are analyzed by the correct methods. Otherwise the results are impossible to interpret in terms of standard recommendations. Cations run on ammonium acetate or sodium bicarbonate extracts, commonly used for determining plant nutrient status of a soil, are useless in diagnosing salinity and sodium problems.

Interpreting the Results

Laboratory results may have to be converted from one set of units to another in order to use the commonly recommended standards. Boron concentration, pH, exchangeable sodium percentage (ESP), sodium adsorption ratio (SAR), percent lime and percent gypsum data usually do not need to be changed. Electrical conductivity (EC), cation exchange capacity (CEC) and the cation and anion concentrations should be converted to the proper units. These units and their conversion factors are shown in Table 2.

If the SAR has not been calculated, the cations must be converted to meq/l. Using meq/l units, the sodium adsorption ratios (SAR) are calculated as:

$$\mathrm{SAR} = \frac{\mathrm{Na}}{\left(\frac{\mathrm{Ca} + \mathrm{Mg}}{2}\right)}$$

When calculating SAR, first add Ca and Mg, then divide by 2. Next, take the square root of this number. Finally, divide the Na value by the value just calculated. If this exact order of calculations is not followed, the correct value will not be obtained. If the units are mmole/l or mole/m^3, the calculation can be made as described except that the Ca + Mg is not divided by 2 before taking the square root.

Quite often a value for adjusted SAR (SAR_{adj}) will be given with water or soil analyses. When used for soil samples, the calculation procedure is being incorrectly used. SAR_{adj} should be used only for irrigation water. This calculation takes into consideration the fact that the water will undergo chemical reactions that will change the effective SAR of the water moving through the soil. The final SAR is affected by the pH and the carbonate and bicarbonate in the irrigation water. In some cases, lime ($CaCO_3$) will dissolve from the soil, lowering the SAR; in other cases, lime will precipitate from solution and the SAR will increase.

Management To Remove or Minimize Soluble Salt or Sodium Problems

Once the salinity source and types of salts have been identified, a management plan can be developed to make the best use of the available resources.

Saline Soils irrigated with good quality water, in the absence of a shallow water table, will usually reclaim themselves as the salts are leached below the root zone. Initially, the rate of reclamation will depend on the amount of water traveling through the profile. After that, the soil salinity will be a function of the water quality, leaching fraction and mineral weathering. If the salts came from a shallow water table, the water table must be lowered by intercepting the incoming water or by providing drainage before reclamation can be accomplished. In some situations, lowering a water table may not be economical, and an alternate land use might be a better choice. Once the water table is lowered, leaching the soluble salts with good quality water is all that is generally needed. **Additions of soil amendments such as sulfur, gypsum or other calcium salt materials do not help reclaim saline soils.**

Normal Soils irrigated with good quality irrigation water should produce most crops without problems as long as soil drainage is adequate.

Saline-Sodic Soils irrigated with good quality water, in the absence of a shallow water table, will change to sodic soils if the soluble salts are leached out of the profile without addition of calcium to replace the exchangeable sodium. This happens as the EC decreases while the SAR remains high. The exception to this is when naturally occurring gypsum is present in the profile near enough to the surface that plowing can mix the gypsum with the surface soil. If the salinity and sodium are coming from a shallow water table, reclamation must include drainage or intercepting the ground water. As the salts are leached from the soil, calcium must be available to the system. Calcium can be added

Table 2. Conversion factors for salinity terms.

	Column A	To convert Column A to Column B, multiply by**	Column B
CEC	meq/100g	10.0	meq/kg
CEC	cmole (+ charge)/kg	10.0	meq/kg
EC	dS/m	1.0	mmhos/cm
	S/m	10.0	mmhos/cm
	µmhos/cm	0.001	mmhos/cm
	ppm total dissolved solids	0.0016	mmhos/cm
Ca	ppm*	0.050	meq/l
	mmol/l or mole/m³	2.0	meq/l
Mg	ppm*	0.082	meq/l
	mmol/l or mole/m³	2.0	meq/l
Na	ppm*	0.043	meq/l
	mmol/l or mole/m³	1.0	meq/l
K	ppm*	0.026	meq/l
	mmol/l or mole/m³	1.0	meq/l
Cl	ppm*	0.028	meq/l
	mmol/l or mole/m³	1.0	meq/l
SO_4	ppm*	0.021	meq/l
	mmol/l or mole/m³	2.0	meq/l
CO_3	ppm*	0.033	meq/l
	mmol/l or mole/m³	2.0	meq/l
HCO_3	ppm*	0.016	meq/l
	mmol/l or mole/m³	1.0	meq/l

*ppm is the same as milligram per kilogram (mg/kg) or milligram per liter (mg/l).

**Example: to convert 40 ppm Ca to meq/l, multiply 40 ppm × 0.050 = 2 meq Ca/l.

as gypsum or calcium chloride. If the soil contains lime near the surface, sulfur, sulfuric acid or iron (ferrous) sulfate can be added to dissolve lime. This results in formation of more soluble gypsum ($CaSO_4$), making calcium available in the soil solution. Adding these amendments is of little value unless leaching also takes place.

Sodic Soils irrigated with good quality water nearly always present infiltration and permeability problems. The high sodium causes the soils to disperse, which reduces water intake and movement in the soil. If a high water table is part of the problem, it must be lowered as the first step in the reclamation process. Reclamation of sodic soils requires reducing the ESP to below 6 to 12 (depending on soil texture and irrigation method) by increasing the exchangeable calcium concentration or by increasing the EC to more than 4 mmhos/cm. High calcium, saline water, if available, can be used to increase the infiltration rate by increasing the soluble calcium and the EC. Then, as the sodium is replaced, better quality water can gradually be used.

If gypsum is used for sodic soil reclamation, the "gypsum requirement" is calculated to determine the amount of gypsum needed to reclaim the soil to a particular depth. A method for calculating gypsum requirement is given in the glossary. Other choices include adding soil amendments such as sulfur, sulfuric acid or ferrous sulfate to soils that contain lime or adding soluble calcium salts such as calcium chloride.

Soil amendments do very little good on the soil surface and must be incorporated to aid reclamation. Coarse organic materials that decompose slowly, such as straw, cornstalks or sawdust or wood shavings used for animal bedding, can help open up sodic soils when used with other reclamation practices. Heavy manure or old alfalfa hay applications worked into the soil dissolve lime and release calcium as they decompose.

Sodic soils generally do not contain natural gypsum in the surface; otherwise they would be saline-sodic. Sodic soils are usually the most expensive soil type to reclaim. Under many conditions, reclamation may not be economical.

Irrigation Water can be the salt or sodium source. If salinity problems have developed from salts and minerals in the irrigation water, only a few options are available. The most desirable option would be to use better quality irrigation water (lower salt and/or sodium). If this is not possible, leaching salts from the soil might be possible during the non-cropping season. Often, it is feasible to irrigate late in the fall so the soil is wet going into the winter. Winter precipitation will then be more effective in moving salts below the root zone. When the total salt load in the irrigation water is low, but the SAR or SAR_{adj} is high, use of the water will increase soil ESP. Adding gypsum to the water can lower the SAR_{adj} and overcome an otherwise undesirable cation ratio in the water. Low salt, high SAR irrigation water treated with sulfuric acid can also be satisfactorily used on soils containing lime.

Shallow water tables can and do develop from overapplication of irrigation water over an entire irrigation project. Salinity gradually becomes a problem as the water evaporates from the soil surface. If only one farmer in an area applies less water, his problem increases faster than his neighbor who continues to over-irrigate because more salts move up from the water table below his soil. Under these conditions, it may become mandatory to require all irrigators to use less water before the overall problem can be resolved. Legal problems may arise from implementing this approach even though it would be in everyone's best interest.

Choosing the right crops and best management practice will increase the chances for successful crop production and soil reclamation. Each crop and plant species has its own tolerance to high pH and soil salinity. Soil moisture content also has a strong influence on plant reactions to high pH and salts contained in the soil. Table 3 shows a sample of available data that can be used to help choose crops and ornamentals on the basis of soil salinity. Tables are also available for pH, boron, ESP and water quality sensitivity for different crops.

Seedlings are usually more sensitive to salt than are established or more mature plants. This is because the seedling roots are in the upper part of the soil profile, which is often saltier and dryer than deeper in the profile. Seedlings require time to produce sufficient sugars in the sap to offset the osmotic effect of the salts in the soil solution. This greater susceptibility to salt injury in seedlings can often be minimized by preplant irrigation. Preirrigation increases the soil water content and flushes some of the salt deeper into the soil. Seeding in the bottom of irrigation furrows used for preirrigation often helps the young seedlings survive. Additional light irrigations are also helpful after planting or emergence to allow the tender seedlings time to become established. Increasing the soil water content dilutes most salts, thus lessening the salt effect on plants. An irrigator may have a choice between two or more waters of unequal quality. When possible, the less salty water should be used to establish seedlings and the poorer quality water can be used on more mature or more salt-tolerant crops.

Irrigators have used "sulfur burners" to mix sulfur dioxide with irrigation water to lower the SAR of the water. In theory, this should work in reclaiming saline-sodic and sodic soils, but it will not work if the irrigation water has a high sodium concentration (high SAR). The main drawback to sulfur burners is the cost per pound of sulfur applied to the field. These systems may apply only a few hundred pounds of sulfur dioxide per acre, while the actual sulfur needed for reclamation is to a minimum of a few tons per acre to produce a measurable result. It may be cheaper to apply a ton of gypsum or sulfur by conventional methods than to apply a hundred pounds through a sulfur burner.

Table 3. Relative productivity of crops at increasing EC (mmho/cm) in the root zone.[1]

Plant name	Scientific names	Electrical conductivity (mmhos/cm)														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		Relative yield														
Alfalfa	*Medicago sativa*	100	100	93	85	78	71	64	56	49	42	34	27	20	12	
Apple	*Malus sylvestris*	100	91	75												
Barley, forage	*Hordeum vulgare*	100	100	100	100	100	100	93	86	79	72	65	58	51	44	37
Barley, grain	*Hordeum vulgare*	100	100	100	100	100	100	100	100	95	90	85	80	75	70	65
Bean	*Phaseolus vulgaris*	100	81	62	43	25	6	0								
Beet	*Beta vulgaris*	100	100	100	100	91	82	73	64	55	46	38	29	20	11	2
Broccoli	*Brassica oleracea*	100	100	98	89	80	71	61	52	43	34	25	16	6	0	
Cabbage	*Brassica oleracea* Var. Capitata	100	98	88	79	69	59	50	40	30	20	11	1	0		
Carrot	*Daucus carota*	100	86	72	58	44	30	15	1	0						
Corn, forage	*Zea mays*	100	99	91	84	76	69	61	54	47	39	32	24	17	10	
Corn, sweet	*Zea mays*	100	96	84	72	60	48	36	24	12	0					
Cucumber	*Cumcumis sativus*	100	100	94	81	68	55	42	29	16	3	0				
Fescue	*Festuca clatior*	100	100	100	99	94	89	84	78	73	68	62	57	52	47	41
Grape	*Vitis* spp.	100	95	86	76	66	57	47	38	28	18	9	0			
Juniper	*Juniperus chinensis*	100	91	81	72	63	54	45	36	27	18	9	0			
Lettuce	*Latuca sativa*	100	91	78	65	52	39	26	13	0						
Meadow Foxtail	*Alopecurus pratensis*	100	95	85	76	66	56	47	37	27	17	8	0			
Muskmelon	*Cucumis melo*	100	100	95	80											
Onion	*Allium cepa*	100	87	71	55	39	23	6	0							
Orchardgrass	*Dactylis glomerata*	100	97	91	84	78	72	66	60	53	47	41	35	29	22	16
Pea	*Pisum sativum* L.	100	100	90												
Peach	*Prunus persica*	100	94	73	52	31	10	0								
Pear	*Pyrus* spp.	100	91	75												
Plum	*Prunus domestica*	100	91	73	55	36	18	0								
Potato	*Solanum tuberosum*	100	96	84	72	60	48	36	24	12	0					
Radish	*Raphanus sativus*	100	90	77	64	51	38	25	12	0						
Raspberry	*Rubus ideaus*	100	80	62												
Rose	*Rosa* spp.	100	74	36	0											
Ryegrass, perennial	*Lolium perenne*	100	100	100	100	100	97	89	82	74	67	59	52	44	36	29
Safflower	*Carthamus tinctorius*	100	100	100	100	100	100	97	90	85	80	75	50			
Sorghum	*Sorghum bicolor*	100	100	100	100	98	90	84	78	70	63	56	50	43	36	29
Squash	*Cucurbita maxima*	100	100	90	74											
Strawberry	*Fragaria*	100	67	33	0											
Sugarbeet	*Beta vulgaris*	100	100	100	100	100	100	100	94	88	82	76	71	65	59	53
Tomato	*Lycopersicon esculentum*	100	100	95	85	75	65	55	46	36	26	16	6	0		
Trefoil, birdsfoot	*Lotus corniculatus tenuifolium*	100	100	100	100	100	90	80	70	60	50	40	30	20	10	0
Wheat	*Tricum aestivum*	100	100	100	100	100	100	93	86	79	71	64	57	50	43	36
Wheatgrass, crested	*Agropyron desertorum*	100	100	100	98	94	90	86	82	78	74	70	66	62	58	54
Wheatgrass, fairway	*Agropyron cristatum*	100	100	100	100	100	100	100	97	90	83	76	69	62	55	48
Wheatgrass, tall	*Agropyron elongatum*	100	100	100	100	100	100	100	98	94	89	85	81	77	73	68
Wildrye, beardless	*Elymus triticoides*	100	100	98	92	86	80	74	68	62	56	50	44	38	32	26

[1] From Bresler, E., B. L. McNeal and D. L. Carter. 1982. Saline and Sodic Soils, Springer-Verlag, New York.

Summary

To remove soluble salts from the soil, three things have to happen: (1) less salt must be added to the soil than is removed; (2) salts have to be leached downward through the soil and; (3) water moving upward from shallow water tables must be removed or intercepted to avoid additional salts moving back to the soil surface. In sodic and saline-sodic soils, the exchangeable sodium must also be replaced with another cation, preferably calcium, and the sodium must be leached from the root zone.

Soil amendments (sulfur, gypsum, iron sulfate and sulfuric acid) are only beneficial on sodic and saline-sodic (with no gypsum) soils, and only when leaching takes place. These materials are added to replace the sodium so it can be leached from the soil. If high exchangeable sodium is not a problem, as in normal or saline soils, these materials will not be beneficial except when the sulfur is needed as a plant nutrient. If a soil contains natural gypsum, even in a saline-sodic soil, amendments will be of little use.

County agricultural agents can usually provide additional information or refer you to soil specialists or soil scientists who have experience with saline or sodic soil problems. Soil Conservation Service personnel are often a good source of help. An on-site inspection of your particular situation may also allow these specialists to be more helpful.

Glossary of Terms for Salt- or Sodium-affected Soils

Alkali or alkali soil:

An old term that is no longer used in soil science. See saline-sodic and sodic soil.

Amendment, soil:

Any material such as lime, sulfur, gypsum, sawdust, sand or straw used to alter the physical or chemical properties of a soil, in contrast to fertilizers, which are added to supply plant nutrients.

Anion:

A negatively charged ion such as chloride (Cl^-) or group of atoms such as sulfate (SO_4^{2-}), carbonate (CO_3^{2-}) or bicarbonate (HCO_3^{4-}).

Cation:

A positively charged ion such as calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+) and potassium (K^+), or small group of atoms such as ammonium (NH_4^+).

Cation exchange:

The interaction between a cation in solution and another cation on the surface of a negatively charged material such as clay or organic matter.

Cation exchange capacity (CEC):

The total quantity of cations that can be exchanged on a unit amount of soil material, expressed as milliequivalent per 100 grams of soil (mg/100g), millimoles of charge per kilogram of soil [mmol (+ charge)/kg] or as centimoles of charge per kilogram of soil [cmol (+ charge)/kg].

Dispersion:

Breaking up of "clumps" of soil particles or aggregates into individual soil particles. Soil aggregates form larger, more continuous soil pores than do soil particles. The larger pores provide better water and air movement.

Electrical conductivity (EC):

The ease with which electrical current passes through water is proportional to the salt concentration in the water. Consequently, total salt concentration in a soil or irrigation water can be readily estimated by measuring the EC. The higher the EC, the greater the salt concentration.

Evapotranspiration:

Combined water use by plants and water evaporated from the soil surface in a given time period. Usually expressed as inches of water or millimeters (mm) of water per day.

Exchangeable sodium percentage (ESP):

That percentage of the cation exchange capacity filled by sodium. It is calculated as:

$$\text{ESP} = \frac{\text{exchangeable sodium}}{\text{cation exchange capacity}} \times 100$$

Field capacity (field moisture capacity):

The water content remaining in a soil 2 to 3 days after it was saturated and then allowed to drain, with no evapotranspiration taking place. The amount of water a soil will hold against gravitational drainage into a well-drained subsoil.

Gypsum requirement (GR):

This is the approximate tons of gypsum needed per acre to lower the ESP of the soil to a desired level and is calculated as:

$$\text{GR} = (\text{present ESP-desired ESP}) \times \text{CEC} \times 0.021$$

The factor of 0.021 assumes CEC is in meq/100g or cmol (+ charge)/kg units. If CEC is in mmols (+ charge)/kg, the factor is 0.0021. These factors assume 80 percent reclamation efficiency and a desirable SAR_{adj} in the irrigation water.

Infiltration rate:

The maximum rate at which water can enter the soil under a specified set of conditions, including water ponded on the soil surface.

Leaching:

The removal of soluble salts from the soil by the downward movement of water through the soil.

Leaching fraction (LF):

That fraction of the infiltrated irrigation water (water entering the soil surface) that percolates below the root zone.

$$\text{LF} = \frac{\text{deep drainage water}}{\text{infiltrated irrigation water}}$$

Osmotic potential:

The water pressure exerted across a cell wall or semipermeable membrane caused by an unequal concentration of salts or sugars on the two sides of the cell wall or membrane. Water will move from the side with the lowest salt or sugar concentration through the membrane into the area with the higher salt or sugar concentration.

Parts per million (ppm):

Concentration based on the number of parts of solute (salt) in a million parts of solution, i.e. 15 ppm sodium choride is the same concentration as having 15 pounds of sodium chloride in 1 million pounds of solution. This is also expressed as mg/l or mg/kg.

pH:

A measure of the acidity or basicity of a material or solution. Less than 7 is acidic and more than 7 is basic, 7 being neutral. The pH is measured with an electrode pH meter or colored dyes.

Sodium adsorption ratio (SAR):

The SAR of the soil solution or irrigation water is a relationship between Na^+ and Ca^{2+} plus Mg^{2+} concentrations that predicts the Na^+ status of the soil exchange complex. It is calculated as:

$$\text{SAR} = \frac{\text{Na}}{\left(\frac{\text{Ca} + \text{Mg}}{2}\right)}$$

where the cation concentrations are expressed as milliequivalent/l. If the units are mmol/l or moles/m³, then the Ca + Mg is not divided by 2.

SAR_{adj}:

The SAR_{adj} is the SAR of the irrigation water, corrected for the effect of carbonate and bicarbonate concentration and pH in the water, on the effect of the soil ESP. SAR_{adj} for soil extract data is an incorrect use of the theory behind its calculation.

Water table:

The upper surface of shallow ground water, or that level below the soil surface where the soil is saturated with water. Water standing in a hole dug into the soil shows the surface of a water table.

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