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Salinity Control in Irrigation Agriculture

TEXAS AGRICULTURAL EXPERIMENT STATION
R. D. LEWIS, DIRECTOR, COLLEGE STATION, TEXAS

SUMMARY

Both the quality of water available and the soil management practices influence the results obtained with salty irrigation waters. For most successful use of saline waters, apply the following principles:

Test water and soil periodically and use these analyses as a basis for planning management practices. TEST — DON'T GUESS.

Apply water uniformly by using a properly designed irrigation system and by leveling where necessary.

Apply enough water for the crop plus enough to keep salt leached to a satisfactory level. A heavy preplant irrigation may be desirable.

Irrigate more often than necessary under non-saline conditions.

Provide adequate drainage. The free water table should be at least 5 to 6 feet below the surface.

Select crops tolerant to your salt conditions.

Plant good seed under optimum moisture and temperature conditions.

Fertilize to replace nutrients lost by leaching and to maintain adequate fertility.

Use soil-improving grasses or legumes to maintain good soil structure and to aid water infiltration and penetration.

Soil amendments, such as gypsum and sulfuric acid, do not control salt. Amendments often are beneficial where sodium is a problem.

Consult your county agricultural agent, experiment station or other agricultural adviser for assistance on your problems.

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Salinity Control in Irrigation Agriculture

PAUL J. LYERLY and DONALD E. LONGENECKER*

A PERMANENT, PROSPEROUS IRRIGATED AGRICULTURE is dependent on an adequate supply of irrigation water of satisfactory quality. The terms "adequate supply" and "satisfactory quality" are difficult to define since each is influenced by the other, and both are influenced by the chemical and physical nature of the soil, climate, adequacy of drainage, crops grown and various farming practices.

In many cases, successful irrigation farming is more dependent on the management practices followed than on the quality of water available. All too often too much emphasis is placed on attempting to answer the question, "How good is this water?" rather than "How can this water be used best?" Frequently, too much attention is given to the "toxic limits" of salt concentration and not enough emphasis directed toward the selection of suitable crops and adjustment of tillage and irrigation practices to the water which is available.

ALL WATERS CONTAIN SALTS

All waters from surface streams and underground sources contain dissolved substances known chemically as salts. Ocean water contains approximately 3 percent salts, or 40 tons of salts per acre-foot of water. Waters used for irrigation generally contain .1 to 5 tons of salt per acre-foot of water.

In general terms, salt is thought of as table salt; however, thousands of different salts are known. Examples of common salts in irrigation water are table salt (sodium chloride), Epsom salt (magnesium sulfate), gypsum (calcium sulfate), muriate of potash (potassium chloride) and baking soda (sodium bicarbonate). In this publication, the various salts found in irrigation water will be referred to collectively as *salt*.

The total salt content in surface and underground waters varies widely. Salt is dissolved from the soil and rock materials through which the water must seep before becoming available for irrigation. Mountain streams often contain less than one-tenth ton of salt per acre-foot of water. Drainage waters and ground waters in desert valleys may contain as much as 10 to 15 tons of salt per acre-foot.

Ground waters often vary widely in total salt content at different locations in the same general area and at various depths in the underground layers of the soil profile.

In addition, waters differ greatly in the kinds of salt present. Some waters are relatively high in sodium salts, such as table salt and baking soda, while others are relatively high in calcium or magnesium salts. The relative proportion of the various salts is of considerable importance.

SALT-AFFECTED SOILS AND IRRIGATION

A salt-affected soil is one in which salt has accumulated sufficiently to reduce or interfere with crop yields. The source of the salt that accumulates in a soil usually is the irrigation water. In some cases, however, the soil may have been salty in the virgin state, or the salt accumulation may have resulted from a high water table.

Most irrigation waters do not contain a sufficient concentration of salt to be greatly injurious to plant growth. However, since all surface and underground waters do contain salt, the application of water by irrigation adds salt to the soil. The salt applied remains in the soil unless it is flushed out in the drainage water or is removed in the harvested crop. With salt being applied with each irrigation, any condition or combination of conditions which allows the salt to accumulate in the soil will produce a salty soil.

Since the development of salty soils is a process of salt accumulation, salt-affected soils can be associated with either good or poor quality water. Figures 1 and 2 show the effect that soil type and management practices may have on the results obtained from using saline water. Obviously, the more salt an irrigation water contains, the greater will be the likelihood for salt conditions to develop.

CHARACTERISTICS OF SALT-AFFECTED SOILS

Three types of salt-affected soils occur: saline soil, nonsaline-sodic soil and saline-sodic soil.[1] Since different management and reclamation practices may be required, it is important to distinguish among these different salt conditions.

Saline Soils

A saline soil is one which contains sufficient soluble salt to interfere with the growth of most plants. Sodium salts are present, but in relatively low concentration in comparison with calcium and magnesium salts. Saline soils often are recognized by the presence of white crusts on the soil, by spotty stands and by stunted and irregular plant growth. Ordinarily the pH is lower than 8.5. Saline soils generally are floc-

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*Respectively, superintendent and assistant agronomist, El Paso Valley Experiment Station, Ysleta, Texas.

culated, and the permeability is comparable with that of similar non-saline soils.

The principal effect of salinity is to reduce the availability of water to the plant. In cases of extremely high salinity, there may be curling and yellowing of the leaves, or firing in the margins of the leaves or actual death of the plant. Long before such effects are observed, the general nutrition and growth physiology of the plant will have been altered.

Nonsaline-Sodic Soils

A nonsaline-sodic soil is relatively low in soluble salts, but contains sufficient exchangeable (adsorbed) sodium to interfere with the growth of most plants. Exchangeable sodium differs from soluble sodium in that it is adsorbed on the surfaces of the fine soil particles. It is not leached readily until displaced by other cations such as calcium or magnesium. These soils often are strongly alkaline, with pH readings usually between 8.5 and 10.0. Plant nutrients, such as iron and phosphorus, become less available to plants under conditions of high pH.

As the proportion of exchangeable sodium increases, soils tend to become dispersed, less permeable to water and of poorer tilth. High sodium soils usually are plastic and sticky when wet, and are prone to form clods and crusts on drying. These conditions result in reduced plant growth because of inadequate water penetration, poor root aeration and soil crusting. Nonsaline-sodic soils occur frequently in small and irregular areas, and often are referred to as "slick spots" or "black alkali" areas.

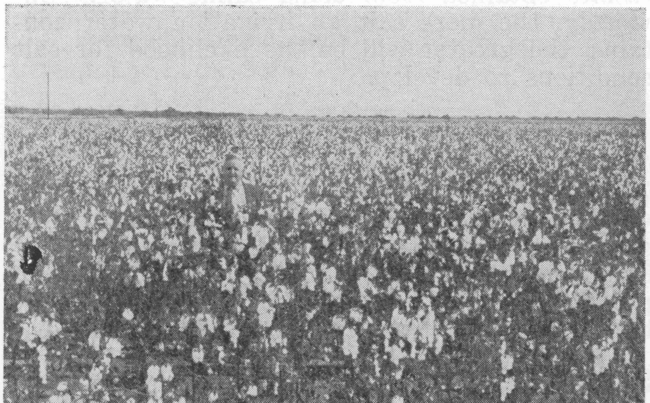

Figure 1. High yields of cotton were obtained in 1951 from this field near Dateland, Arizona, with water containing more than 5 tons of salt per acre-foot. The cotton was planted and grown in the furrows. Water in excess of that needed by the crop was applied to prevent excessive salt accumulation. This field had been in production since 1940 and until 1950 was cropped with Sudangrass, alfalfa and grain sorghum. Picture courtesy Soil Conservation Service.

Sodic soils usually develop because of excessively high sodium in proportion to calcium and magnesium. This may result from a high percentage of sodium in the irrigation water or because of the precipitation of calcium and magnesium salts under certain conditions.

Saline-Sodic Soils

Saline-sodic soils contain sufficient quantities of both total soluble salt and adsorbed sodium to reduce the yields of most plants. As long as excess soluble salts are present, the physical properties of these soils are similar to those of saline soils. The pH is seldom higher than 8.5 and the soil generally remains permeable to water. If the excess soluble salts are removed, these soils may assume the properties of nonsaline-sodic soils. This condition is encountered frequently immediately following heavy rains, and may result in the death of young plants.

Both nonsaline-sodic and saline-sodic soils may be improved by the replacement of the excessive adsorbed sodium by calcium and magnesium. This usually is done by applying soluble amendments which supply these cations. Acid-forming amendments, such as sulfur or sulfuric acid, may be used on calcareous soils since they react with limestone (calcium carbonate) to form gypsum, a more soluble calcium salt.

EFFECT OF SALINITY ON PLANT GROWTH

Soil salinity causes poor and spotty stands of crops, uneven and stunted growth and poor yields, the extent depending on the degree of salinity. The primary effect of salinity is that it acts to make water less available to the plant, but toxicity also may occur. As salinity increases, water, while still present, becomes increasingly less avail-

Figure 2. Poor stand of cotton on a saline soil near Pecos. The saline condition of this soil developed in 3 years because of improper management of water containing 3 to 5 tons of salt per acre-foot. Approximately 1.5 bales of cotton were produced the first year in cultivation. A heavy preplant irrigation and planting in the furrows likely would contribute to the restoration of such land.

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[1] Refer to Definitions for technical descriptions. The term "sodic" is used to describe soils high in exchangeable sodium. The term "alkali" also is used in referring to such soils.

TABLE 1. QUANTITY OF SALT ADDED TO SOIL ANNUALLY BY APPLICATION OF 3 ACRE-FEET OF WATER OF VARIOUS SALT CONCENTRATIONS

Tons of salt per acre-foot of water applied	Tons of salt added to the soil 1 year	2 years	3 years	4 years	5 years	6 years
½	1½	3	4½	6	7½	9
1	3	6	9	12	15	18
2	6	12	18	24	30	36
4	12	24	36	48	60	72
6	18	36	54	72	90	108

able to the plant. This is because the osmotic pressure of the soil solution increases as the salt concentration increases. Laboratory tests show that the reduction in plant growth under saline conditions is related closely to the osmotic pressure of the soil solution. Farmers often refer to saline moisture as "dry moisture." This simply means that the soil contains water, but the plants are unable to extract it as readily as from nonsaline soils.

In the case of extremely high salinity, there may be chlorosis, or firing of the margins of the leaves, or actual death of the plants because of toxic effects of such ions as chloride and magnesium. Excessive concentration and absorption of single ions may retard the absorption of other minerals necessary for good growth.

There is no critical point of salinity where plants fail to grow. As salinity increases, growth becomes less and less until the plants become chlorotic and die. Neither is there a definite point of salinity where crop production becomes prohibitive. With increasing salinity, the maximum yield potential becomes progressively less. Usually crop production becomes marginal or uneconomical at some point of salinity considerably below that at which plants fail to grow.

FACTORS AFFECTING SALT ACCUMULATION

The net increase or decrease in salt annually for each acre of land depends on the total volume of irrigation water applied, the salt concentration in the irrigation water, the subsoil drainage and the crop grown.

Large Quantities of Salt Added

Large quantities of salt may be added to the soil each year in the irrigation water, particularily in water of high salinity, Figure 3. The quantity of salt added to the soil by annual applications of 3 acre-feet of water over a 6-year period is shown in Table 1. As the concentration of salt in the irrigation water increases, the application of salt to the soil increases rapidly. Thus, with water containing 4 tons of salt per acre-foot of water, the application of 3-acre-feet of water results in a cumulative application of 12, 24, 36, 48, 60 and 72 tons of salt over a 6-year period. With such water, enough salt is added to the soil each year to approximate 0.4 percent of the soil weight to a depth of 18 inches. This is enough salt to create a severe salinity problem under many conditions—enough to inhibit germination of most seed.

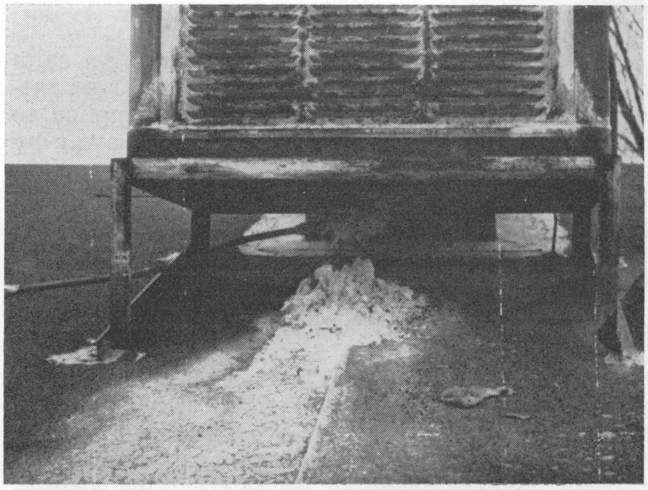

Figure 3. Salt deposit resulting from a small leak in an evaporative cooler illustrates the process by which salts may build up rapidly in the soil.

Little or No Salt Evaporated

Much of the water applied to the soil is lost to the atmosphere by evaporation and by transpiration of plants. None of the salt is so lost. The amount of salt taken up and removed from the soil by plant growth is small for most crops, as shown in Table 2. Fifteen hundred pounds of cottonseed, for instance, contain a total of only about 34 pounds of sodium, calcium, magnesium, sulfate and chloride. Of this total, only about 3 pounds is sodium, the element directly associated with sodic conditions.

TABLE 2. POUNDS OF VARIOUS MINERALS REMOVED FROM THE SOIL BY CROPS IN THE EL PASO AREA

Crop	Yield, pounds per acre	Pounds Sodium	Calcium	Magnesium	Sulfate	Chloride	Total
Sweetclover hay	8,000	17	156	104	69	33	379
Sudangrass hay	10,000	21	34	69	199	67	390
Alfalfa hay	8,000	42	60	49	52	55	258
Barley straw	2,000	14	8	3	28	15	68
Corn silage	30,000	72	58	103	97	103	433
Barley grain	1,000	2	1	1	3	7	14
Sorghum grain	3,000	6	3	5	8	17	39
Cottonseed	1,500	3	2	5	8	16	34
Average	7,938	22	40	42	58	39	202

Salinity Controlled by Leaching

Leaching is the only way by which the salts added in the irrigation water can be removed satisfactorily. Sufficient water must be applied to dissolve the excess salts and carry them away by subsurface drainage. As the quantity of salt in the soil or irrigation water increases, increasing amounts of water must be passed through the root zone to keep the salinity reduced to a concentration low enough for crop production.

Improper Drainage May Cause Salinity

Water will rise 2 to 5 feet or more in the soil above the water table by capillarity. The height to which water will rise above a free water surface depends on soil texture, structure and other factors. Water reaching the surface evaporates, leaving a salt deposit which is typical of saline soils, Figure 4. Many saline soils have developed as a result of a high water table or restricted drainage.

With the necessity of using additional water beyond the needs of the plant to provide sufficient leaching, it is imperative under irrigation that there be adequate drainage for water passing through the root zone. Natural drainage through the underlying soil may be adequate. In cases where subsurface drainage is inadequate, open or tile drains may have to be provided. In no case should the water table be permitted to come nearer than 5 or 6 feet to the soil surface. In some cases, clay lenses or hardpan formations may create a perched water table, and it often becomes necessary to break up these impervious layers by subsoiling, deep plowing or by other means.

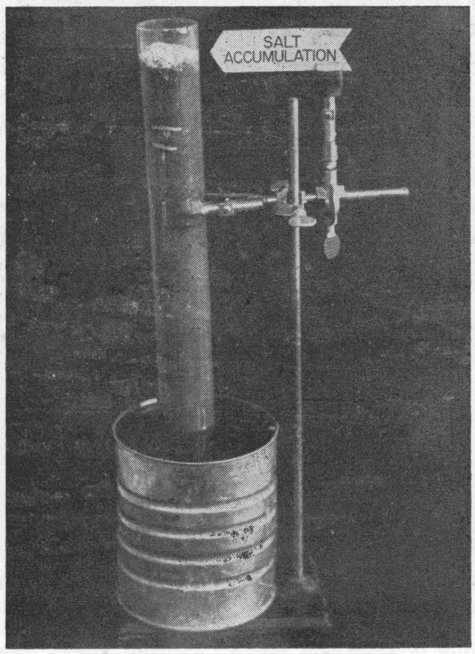

Figure 4. Saline soils often result from a high water table. Water will rise 4 to 6 feet or more in the soil above a free water surface. A salt deposit is left at the surface when water evaporates.

MANAGEMENT PRACTICES AFFECTING SALINITY

Although farming practices vary from one irrigated region to another, many general principles have widespread application for minimizing the effects of salinity.

Crops Vary in Salt Tolerance

Some crop plants can tolerate relatively large amounts of salt. Others are more easily injured. Some may be injured by relatively small amounts of salt. The choice of crops to be grown, then, becomes highly important. Non-tolerant crops cannot be grown successfully on saline soils. As the salt in the water and soil increases, the num-

TABLE 3. RELATIVE SALT TOLERANCE OF VARIOUS CROP PLANTS. GOOD GROWTH AND YIELDS OF THE LISTED CROPS CAN BE EXPECTED AT A SOIL SALINITY BELOW THAT GIVEN IN EACH HEADING[1]

Relatively non-tolerant	Moderately salt tolerant	Relatively salt tolerant	Highly salt tolerant
EC x 10^3 2.0 — 4.0^2	EC x 10^3 4.0 — 6.0^2	EC x 10^3 6.0 — 8.0^2	EC x 10^3 8.0 — 12.0^2
	FIELD CROPS		
Field bean Cowpeas	Sorghum (grain) Corn (field) Castorbean Soybean	Cotton Rye (grain) Wheat (grain) Oats (grain) Rice	Barley (grain) Sugar beet Rape
	FORAGE CROPS		
White clover[3] Alsike clover Red clover Ladino clover Crimson clover Rose clover Burnet clover	Tall fesque Meadow fesque Orchardgrass Millet Sour clover Birdsfoot trefoil	Wheatgrasses Sudangrass Sweetclover Alfalfa Ryegrass Rye (hay) Wheat (hay) Oats (hay)	Alkali sacaton Bermudagrass Barley (hay) Rhodesgrass Blue Panicgrass
	VEGETABLE CROPS		
Lima bean Green bean Celery	Tomato Broccoli Cabbage Pepper Lettuce Sweet corn Onion Pea Watermelon Cantaloupe Squash	Garden beet Kale Spinach Okra	Asparagus
	FRUIT CROPS		
Pear Apple Orange Grapefruit Plum Apricot Peach Strawberry Lemon Avocado	Olive Grape	Pomegranate Fig	Date Palm

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[1] Adapted from USDA Agricultural Handbook 60, U.S. Salinity Laboratory.

[2] Conductivity of saturation extract from the soil, expressed as millimhos/cm at 25° C.

[3] Common name formerly was White Dutch Clover.

ber of crops which can be grown successfully becomes more limited.

The relative salt tolerance of a number of crop plants is shown in Table 3. The tolerance of crops listed may vary somewhat, depending on the particular variety grown, the cultural practices used and the climatic factors. Cotton, for instance, is one of the more salt-tolerant crops, however, American-Egyptian varieties probably are somewhat more salt tolerant under most conditions than Upland varieties. Some crops, such as beets, may be highly salt tolerant as mature plants, but sensitive to salt at the time of germination. Other crops, such as corn, possess less tolerance to salt as growing plants but germinate reasonably well under moderately saline conditions.

Leaching Requirements

The amount of salt added to the soil is determined by the salt content and volume of water applied. The amount of salt removed by leaching is determined, likewise, by the salt content and quantity of water passed below the root zone. As the quantity of salt in the soil or in the irrigation water increases, increasing amounts of water must be passed through the root zone to keep the soil salinity low enough for crop production. Salt-tolerant crops can be grown with less leaching than more sensitive crops. Soil salinity cannot be reduced below the salinity of the water used for leaching.

The approximate percentage of water entering the soil which must be passed through the root zone (leaching percent or requirement[2]) to maintain good yields of salt-tolerant and non-tolerant crops is shown in Figure 5. For water containing 2 tons of salt per acre-foot, approximately 29 percent leaching is required to maintain good cotton yields. This does not mean that cotton cannot be produced with less leaching when using such water. If less leaching is done, however, higher salinity may result in lower yields. Salinity may not be the only cause of reduced yields. It would be inefficient to leach in the amount indicated if the fertility or other conditions were limiting yields.

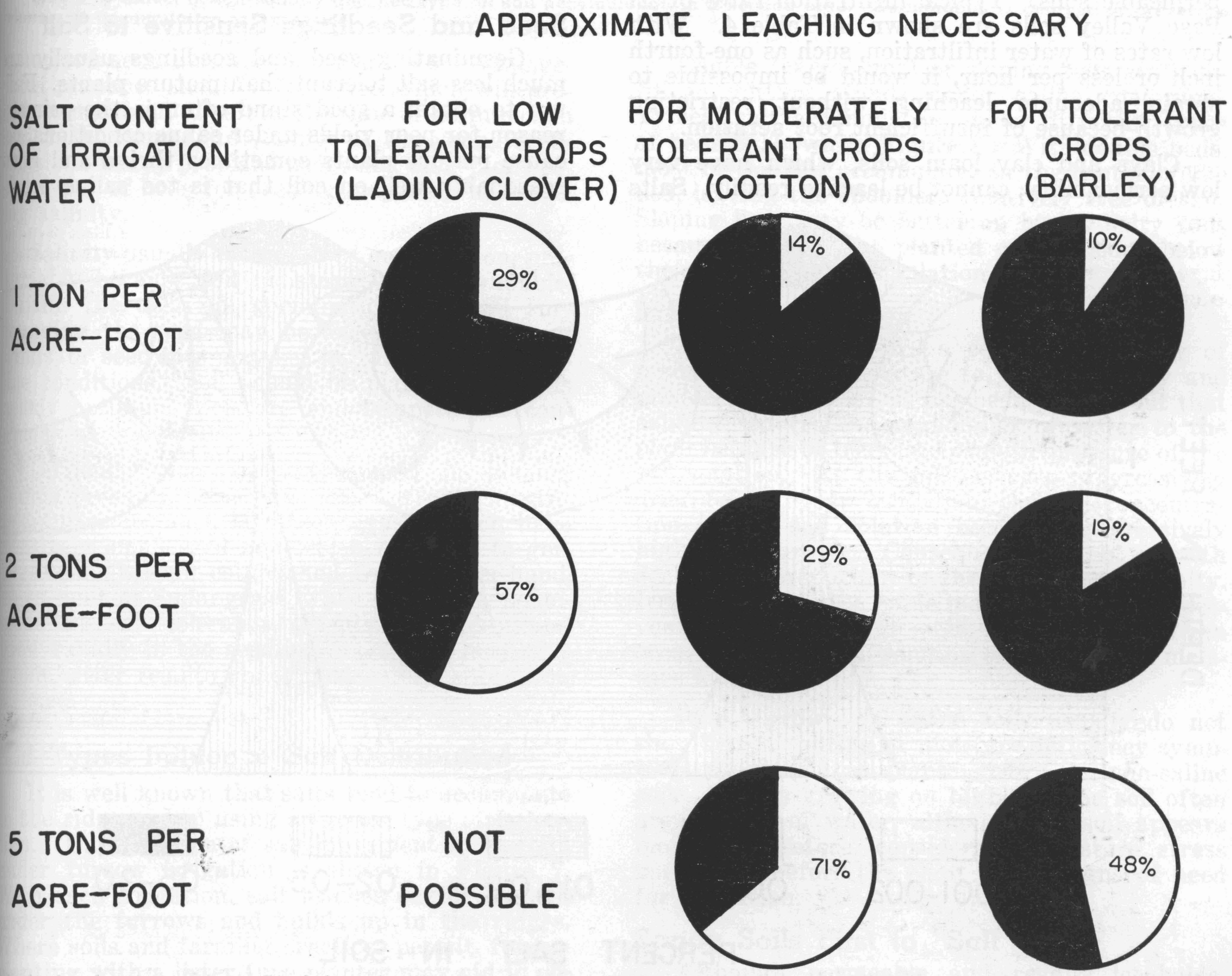

Figure 5. Approximate leaching requirements—percentage of the irrigation water (white area) that must pass below the root zone to prevent an appreciable reduction in crop yields because of a salt accumulation in the soil.

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[2] See page 12 for method used in determining the leaching requirement.

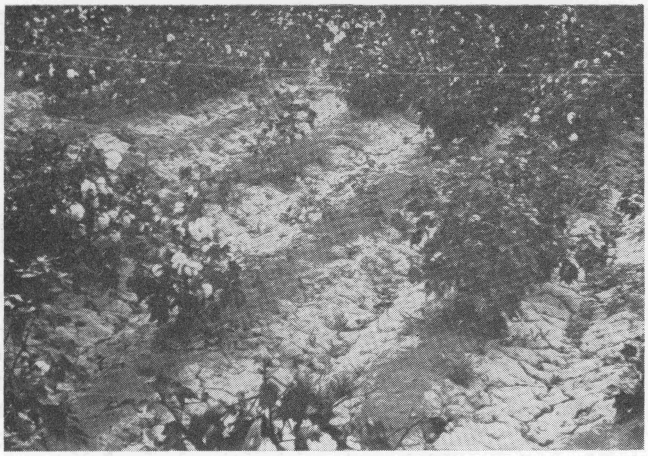

Figure 6. Saline soils result in poor and spotty stands and irregular plant growth. Reasonably good growth of mature plants sometimes may be obtained on soils too salty for good seed germination.

Permeable Soils Essential

The need for applying large quantities of water for leaching when using highly saline irrigation water emphasizes the need for open, easily permeable soils. Typical infiltration rates of El Paso Valley soils are shown in Table 4. With low rates of water infiltration, such as one-fourth inch or less per hour, it would be impossible to obtain adequate leaching without restricting growth because of insufficient root aeration.

Clays and clay loam soils, which have very low permeability, cannot be leached readily. Salts often build up in these finer-textured soils even when low-salt waters are applied. Permeability may be lowered by poor soil structure resulting from too much sodium, from excessive or poorly timed tillage practices or because of poor cropping systems. Chiseling or deep plowing may aid in increasing soil permeability where hardpans, plow soles or clay layers restrict drainage.

TABLE 4. TYPICAL INFILTRATION RATES OF EL PASO VALLEY SOILS[1]

Soil	Infiltration rate, inches per hour	Hours for water to penetrate 3 feet with standing water on surface
Clay	¼ — ½	144 — 72
Clay loam	½ — 2	72 — 18
Sandy loam	2 — 3	18 — 12
Coarse sand	7 — 9	5 — 4

[1] Courtesy of L. Freeman, Soil Conservation Service.

In many instances, the leaching requirement can be handled most satisfactorily by a heavy preplant irrigation, with lighter irrigations used throughout the growing season. The heavy preplant irrigation also serves to lower soil salinity to a minimum at the time of seed germination.

Seed and Seedlings Sensitive to Salt

Germinating seed and seedlings usually are much less salt tolerant than mature plants. Failure to obtain a good stand often is the primary reason for poor yields under saline conditions, because mature plants sometimes thrive and grow reasonably well on soil that is too saline to ob-

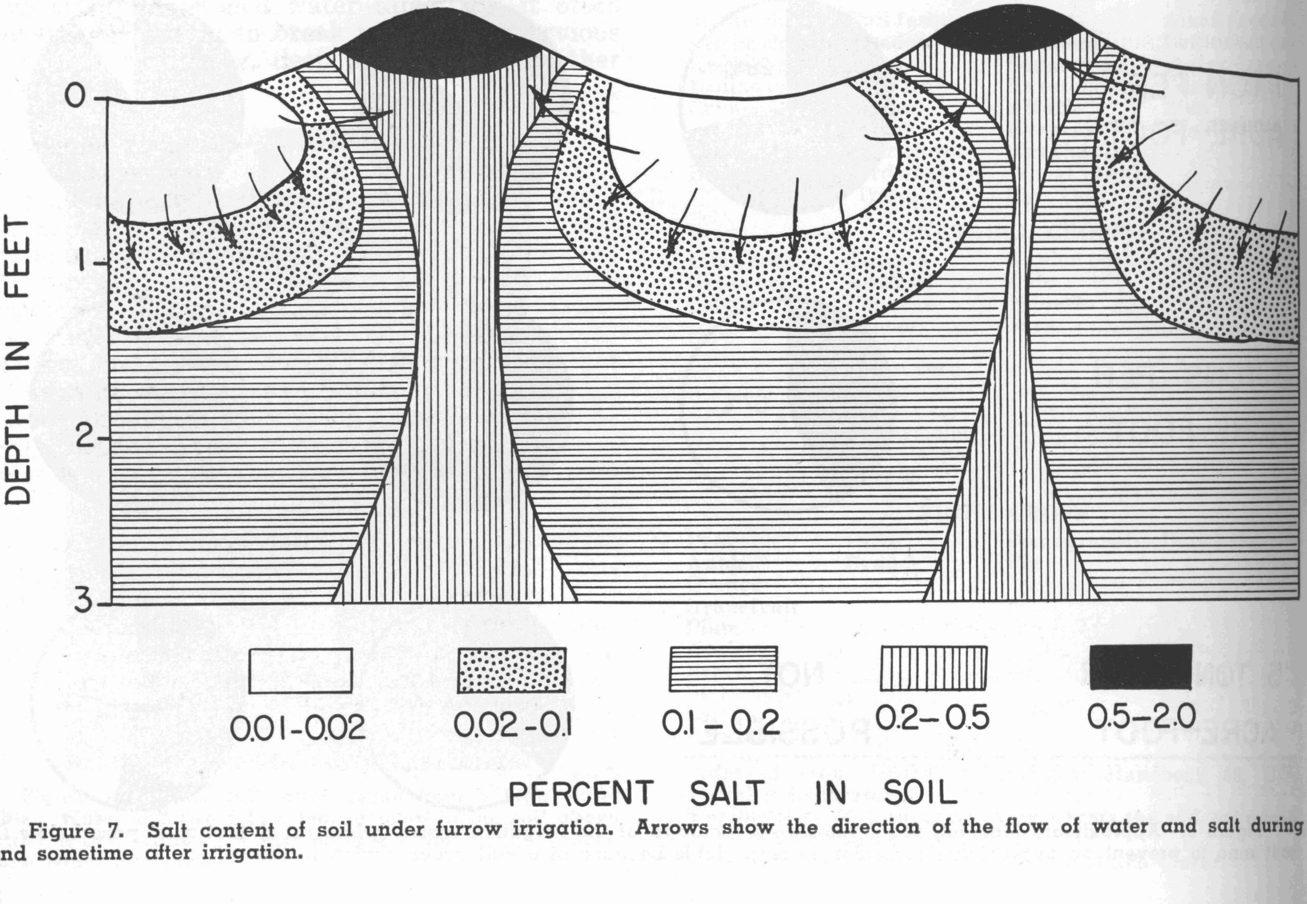

Figure 7. Salt content of soil under furrow irrigation. Arrows show the direction of the flow of water and salt during and sometime after irrigation.

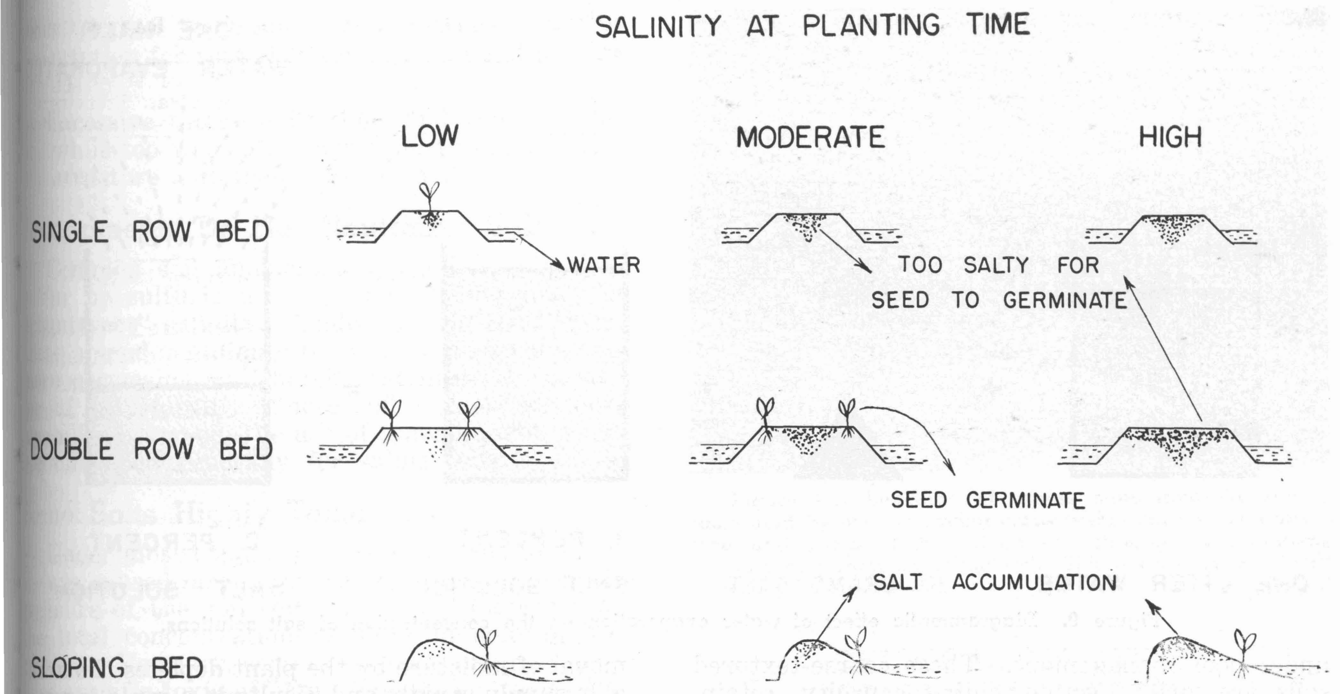

Figure 8. **Effect of soil salinity and bed type on salt accumulation in a seeded area. Germination is delayed or prevented where salt accumulation is excessive.**

tain good seed germination, Figure 6. Management practices should be followed which will provide a minimum of salt at the time of germination and in the immediate vicinity of the young seedlings. A heavy preplant irrigation or use of special types of beds for seeding may help in reducing salinity.

Salinity usually retards seed germination, presumably because soil moisture is less available. During the delay in germination, the soil surrounding the seed may be excessively dried by winds, or seed rots may set in. Hence, under saline conditions, seed should be planted under as nearly optimum moisture and temperature conditions as possible.

Difficulty may be experienced in getting stands (even on non-saline soils) of certain salt-tolerant crops, such as Rhodesgrass, which have relatively small seed and which are slow to germinate and become established. On the other hand, crops, such as Sudangrass, while possessing somewhat less salt tolerance, germinate quickly, and grow rapidly in the seedling stage, and may give much better results under moderately saline conditions.

Bed Types Influence Salt Distribution

It is well known that salts tend to accumulate in the ridges when using a furrow type of irrigation. The direction of salt movement in the soil under furrow irrigation is shown in Figure 7. With each irrigation, salt leaches out of the soil under the furrows and builds up in the ridges. Where soils and farming practices permit, furrow planting with a lister type planter may aid in obtaining stands under saline conditions.

Double (cantaloupe) or sloping beds are helpful in getting stands under saline conditions. Typical salt accumulation under different types of beds is shown in Figure 8. With double beds, most of the salt accumulates in the center of the bed, leaving the shoulders relatively free of salt. Sloping beds may be better on highly salty soils because seed can be planted on the slope below the zone of salt accumulation.

Irrigate More Often

Most plants require a continuous supply of readily available moisture to grow normally and produce high yields. It has been pointed out that salinity reduces the availability of water to the plant because of increased osmotic pressure of the soil solution. As the soil becomes progressively drier following an irrigation, the salt concentration in the soil solution becomes progressively higher, Figure 9. Consequently, plant growth declines in proportion to the increase in salinity. Irrigations must be made more frequently to prevent excessively high salt concentrations from occurring in the soil solution because of low moisture levels.

Plants grown on saline soils usually do not show typical wilting or moisture-deficiency symptoms as readily as plants grown on non-saline soils. Plants growing on highly saline soil often are in need of water, although the soil appears moist. Therefore, considerable moisture stress may occur before the plant shows signs of need for irrigation.

Sandy Soils First to "Salt Out"

Although permeable and readily leachable, sandy soils often are among the first to "salt out"

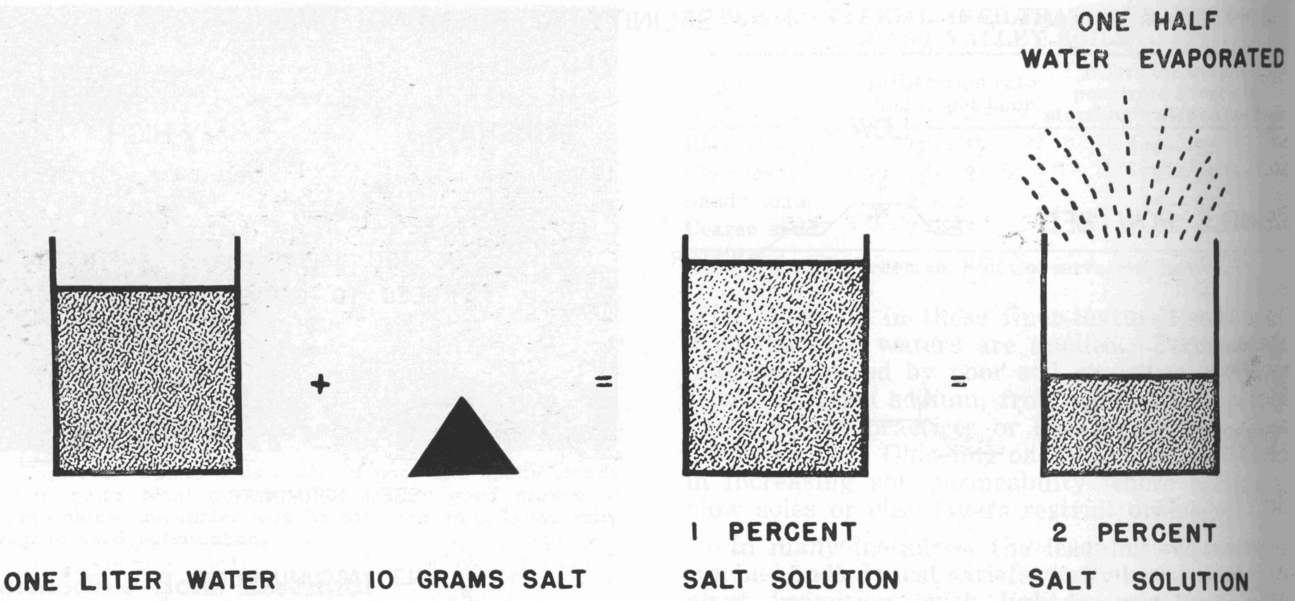

Figure 9. Diagrammatic effect of water evaporation on the concentration of salt solutions.

under poor management. These coarse-textured soils are low in water-holding capacity, retaining only about one-half inch of available moisture per foot of soil depth, compared with about 2 inches for clay soils, Figure 10. With such a relatively small reservoir of available moisture, removal of moisture by the plant depletes the available supply rapidly and results in a rapid increase in salt concentration of the remaining solution, Figure 9. Hence, unless irrigated frequently, sandy soils may show extreme effects of salinity more quickly than clay soils.

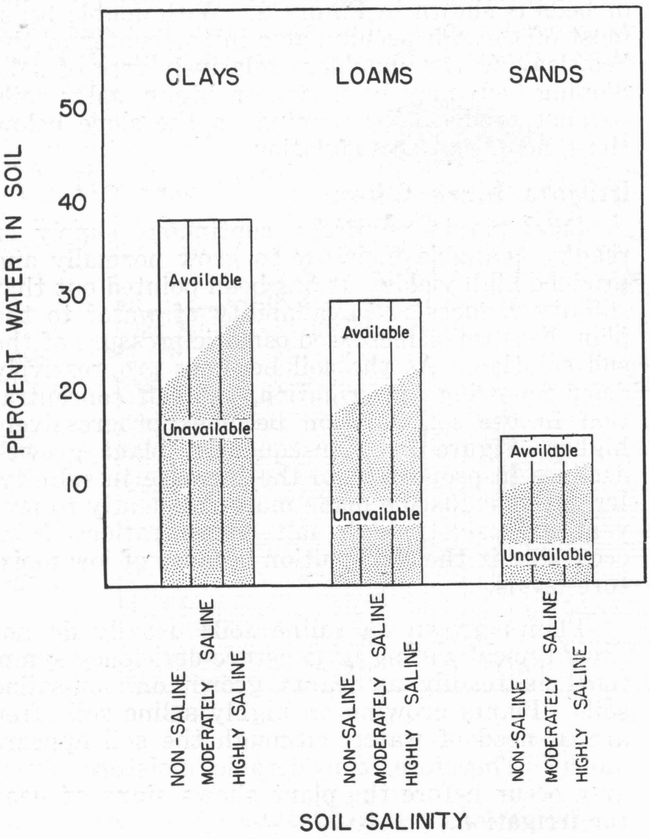

Figure 10. The amount of soil moisture available for plant growth is influenced by both soil texture and soil salinity. Fine-textured soils have a greater water-holding capacity than coarse-textured soils. Saline water is less available to plants than non-saline water.

Level Land for Uniform Water Application

Proper field leveling and a well-planned irrigation system are most helpful in minimizing salinity. Salinity problems are aggravated by field or soil conditions which result in uneven water penetration. High areas and ridges which fail to get sufficient water for leaching usually develop saline conditions resulting in "salted out" spots. Areas with lower than average permeability may develop the same condition. Low areas in the field which are subject to drowning-out encourage the irrigator to cut off the water before the remainder of the field has had sufficient irrigation. Water distribution and penetration must be uniform to bring about uniform leaching of salt.

Commercial Fertilizers May Aid

The need for periodic leaching to remove excess salts has been stressed. Unfortunately, this process also removes soluble plant nutrients from the soil. Nitrogen is especially susceptible to leaching. Periodic applications of commercial fertilizer or manures may be necessary to provide sufficient fertility for good crop production. When the application of large quantities of irrigation water is necessary, smaller, but more frequent fertilizer applications, may be desirable.

Use Good Cropping Practices

It is desirable with saline soils to maintain a good soil structure to encourage water infiltration and penetration, especially on soils which are poor in these respects. The inclusion of legumes, grasses or other green manure crops in the rotation for this purpose may be helpful, Figure 11.

Excessive tillage operations and working the soil while too wet or too dry tend to destroy the soil structure and should be avoided.

Amendments Do Not Neutralize Salt

Common soil amendments, such as gypsum, sulfur or sulfuric acid, do not "neutralize" or "counteract" salinity. Under certain conditions, these amendments may be used to make the soil more permeable and thereby facilitate the leaching of excess salt. Where soil and subsoil permeability are good, the use of amendments is not recommended generally for saline soils.

Some Salts Highly Toxic

Under most conditions, the ill effects of salinity are caused largely by the increase in osmotic pressure of the soil solution, which increases as the total concentration of salts in solution increases. However, certain salts or ions may produce specific toxic effects. This is known as the "specific ion" effect. Boron is extremely toxic to plants, and injury may occur if the boron content of the irrigation water exceeds 2 to 4 parts per million, depending on the particular plants grown. The relative boron tolerance of various plants is shown in Table 5.

Many of the ions commonly occurring in irrigation waters, such as chloride or sulfate, may be toxic when present in large quantities, particularly if their relative proportion to other ions is high. The toxicity may result from the particular ion as such, or by alteration of the general metabolism of the plant because of an unbalanced supply or availability of other nutrients.

TABLE 5. RELATIVE TOLERANCE OF VARIOUS PLANTS TO BORON, ARRANGED ACCORDING TO DECREASING TOLERANCE WITHIN EACH GROUP[1]

Tolerant	Semi-tolerant	Sensitive
Asparagus	Sunflower	Pecan
Palm	Potato	Black walnut
Date palm	Acala cotton	Jerusalem artichoke
Sugar beet	Pima cotton	Navy bean
Mangel	Tomato	American elm
Garden beet	Sweetpea	Plum
Alfalfa	Radish	Pear
Gladiolus	Field pea	Apple
Broadbean	Ragged Robin rose	Grape (Sultanina and Malaga)
Onion	Olive	
Turnip	Barley	Kadota fig
Cabbage	Wheat	Persimmon
Lettuce	Corn	Cherry
Carrot	Sorghum grain	Peach
	Oats	Apricot
	Zinnia	Thornless blackberry
	Pumpkin	Orange
	Bell pepper	Avocado
	Sweet potato	Grapefruit
	Lima bean	Lemon

[1] Ratings made by Eaton, 1935.

Figure 11. Leaching of excess salts from the soil is facilitated by soil improving crops which improve soil structure and permeability. Good soil structure also lessens crusting and cracking of the soil. This is an excellent stand of Sweet Sudangrass.

CHEMICAL ANALYSES OF SOIL AND WATER

Reliable soil and water analyses aid greatly in planning and adjusting management practices to best suit the water and soil available. Periodic water analyses will provide information on the composition and concentration of salt in the irrigation water, which may change from time to time. Soil analyses will indicate whether the saline or sodic condition of the soil is improving or is becoming worse under the farming practices followed. It is important that samples be collected and composited in such a manner that they will represent correctly the water or soil to be analyzed. Soil analyses are made by the Soil Testing Laboratory and water analyses by the State Chemist, both at College Station, Texas. Directions should be obtained first on how to take and send a sample. Ordinarily a fee is charged for these analyses. Many private laboratories also make soil and water analyses.

While numerous types of laboratory tests are available, the analyses described following are most commonly used and most informative in routine salinity tests.

The concentration and composition of dissolved salts determine the suitability of water for irrigation use. Water analyses ordinarily should include: (1) a determination of the total dissolved salts, (2) a determination of the more important ions, such as sodium, calcium, chloride and bicarbonate and (3) a determination of the proportion of sodium to calcium and magnesium.

Routine soil analyses should include the determination of: (1) concentration of salt in the saturation extract, (2) percent of exchangeable sodium, (3) pH and (4) calcium content of the soil, either, as gypsum or calcium carbonate, or as both.

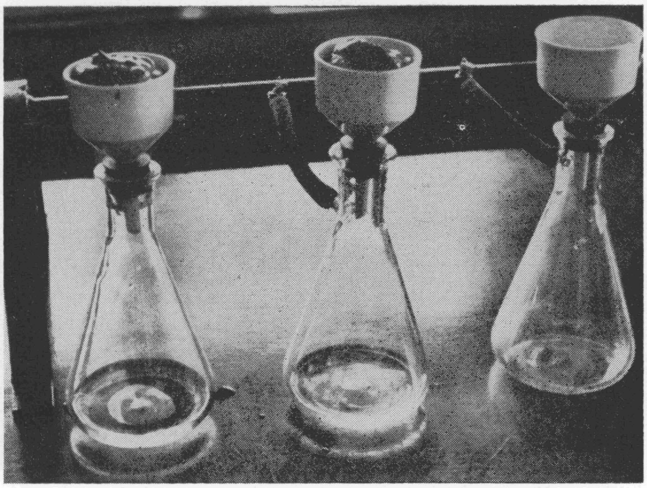

Figure 12. The saline condition in the soil generally is estimated by determining the soluble salt in the "saturation extract." A representative sample of soil is saturated with water and part of the water is extracted by aid of a vacuum for analysis.

The farmer generally thinks in terms of the salt contained in the irrigation water he applies; the plant, however, is influenced by the salt in the soil solution. This is governed by the salt already in the soil as well as the salt in the water applied. A saturation extract is obtained to provide an estimate of the salinity of the soil solution. This is done by saturating the soil with water and then extracting some of the water with the aid of a vacuum, Figure 12. The salt constituents contained in the saturation extract are then determined.

Total Dissolved Solids

The total dissolved solids (salts) may be determined by evaporating a known quantity of water to dryness after filtering to remove suspended matter, then weighing the salt residue. Results are reported in parts per million (p.p.m.), percentage or other units. A more common and faster method is to measure the electrical conductivity of the solution, since the amount of electrical current water will conduct is related closely to the dissolved salt content. The salt concentration may be reported directly in terms of electrical conductivity (ec), or may be converted into approximate parts per million, tons per acre-foot of water (t.a.f.), or other figures more readily visualized in everyday usage, Table 6.

TABLE 6. APPROXIMATE SALINITY VALUES EXPRESSED IN VARIOUS TERMS

Electrical conductivity (ec x 10^6)	Tons per acre-foot (t.a.f.)	Parts per million (p.p.m.)	Grains per gallon
575	½	368	21
1148	1	735	43
2297	2	1470	86
4594	4	2940	173
6891	6	4410	258

Concentration of Specific Ions

Upon dissolving, salts dissociate into particles carrying positive charges (cations) and negative charges (anions). These electrically charged particles are called ions. The proportion or concentration of the various ions is especially important from the standpoint of adsorbed sodium or ion toxicity, or both.

Anions commonly included in water and soil analyses are: chloride (Cl), sulfate (SO_4), carbonate (CO_3) and bicarbonate (HCO_3). Cations commonly analyzed for are: calcium (Ca), magnesium (Mg), sodium (Na) and potassium (K). Nitrates or other ions may be included. Boron tests are made in areas where waters may contain this element in harmful amounts.

Concentrations of the various ions usually are given in parts per million or milliequivalents per liter (meq/l).

Potential Sodium Hazard

Methods commonly used for estimating the potential sodium hazard from use of high sodium water are concerned with the proportion of sodium in solution in relation to the total cation concentration. Of the several methods in use, the determination of sodium percentage is the oldest and most commonly used. The sodium percentage may be defined as the percentage of sodium to the total positive ions present, expressed on an equivalent basis. A more recently developed relation designated as the sodium-adsorption-ratio (sar) appears to give a more reliable estimate of the potential sodium hazard (17).

Waters relatively high in carbonates or bicarbonates have an increased sodium hazard, since calcium and magnesium may be precipitated in the soil as carbonates. Waters containing large amounts of carbonate or bicarbonate tend to precipitate calcium and magnesium carbonates as the soil becomes drier. This results in a corresponding increase in the sodium percentage of the soil solution. The sodium percentage "possible" takes into account calcium and magnesium carbonates that might be precipitated. The excess carbonate plus bicarbonate over calcium plus magnesium is known as the "residual sodium carbonate." Formulas for calculating the sodium percentage, sodium adsorption ratio, sodium percentage "possible" and residual sodium carbonate are shown following. Ion concentrations are expressed in milliequivalents per liter:

$$\text{Sodium percentage (ssp)} = \frac{\text{sodium} \times 100}{\text{sodium} + \text{calcium} + \text{magnesium} + \text{potassium}}$$

$$\text{Sodium adsorption ratio (sar)} = \frac{\text{sodium}}{\sqrt{\dfrac{\text{calcium} + \text{magnesium}}{2}}}$$

$$\text{Sodium percentage “possible”} = \frac{\text{sodium} \times 100}{(\text{sodium} + \text{calcium} + \text{magnesium} + \text{potassium}) - (\text{carbonate} + \text{bicarbonate})}$$

$$\text{Residual sodium carbonate (rsc)} = (\text{carbonate} + \text{bicarbonate}) - (\text{calcium} + \text{magnesium})$$

Exchangeable Sodium Percentage

The percentage of exchangeable (adsorbed) sodium in the soil may have a considerable influence on soil tilth and other properties. It is used as a criterion of a sodic soil and is useful for determining the amount of soil amendment needed for reclamation purposes. While the methods of analyses are somewhat involved, the formula for calculating the exchangeable sodium percentage is:

$$\text{Exchangeable sodium percentage (esp)} = \frac{\text{Exchangeable sodium (meq/100 gm. soil)}}{\text{Cation exchange capacity (meq/100 gm. soil)}} \times 100$$

The cation exchange capacity is defined as the total adsorptive capacity of the soil for cations.

pH

The term “pH” is a measure of the acidity or alkalinity as determined by the hydrogen ion concentration. Pure water with a pH of 7.0 is neutral — neither acid nor alkaline. A solution with a pH lower than 7.0 is acid, while a pH above 7.0 is alkaline. The pH scale ranges from 0 to 14 on a logarithmic scale. Nonsaline-sodic soils generally have pH values of 8.5 or above. Many nutrients become relatively unavailable to plants at such high pH values.

Leaching Requirement

The leaching requirement is the percentage of irrigation water entering the soil which must pass below the root zone to reduce the soil salinity to a desired level. For areas having relatively low rainfall and rather saline irrigation water, a practical estimate of the amount of leaching necessary may be obtained from the following formula:

$$\text{Leaching requirement} = \frac{\text{ec of irrigation water}}{\text{ec permissible in drainage water}}$$

Under certain conditions, it may be desirable to use other formulas (not given here) which take into consideration rainfall, salt removal by plants, precipitation of salts in the soil and toxic ions.

The concentration of salt which can be tolerated in the soil is somewhat relative, depending on the varieties and crops grown, climate, frequency of irrigation and other management practices, and on the yields expected. Table 3 is useful for estimating the permissible soil salinity level for various crops. To obtain good yields, the maximum soil extract concentration probably should be kept below a conductivity of 4 mmhos/cm for sensitive crops, such as beans or Ladino clover, should not exceed 8 mmhos/cm for relatively tolerant crops, such as alfalfa and cotton, or 12 mmhos/cm for highly tolerant crops, such as barley. Somewhat higher salt concentrations may be permissible if some reduction in yield is acceptable or more economical.

Gypsum

Gypsum (calcium sulfate) is found in soils in arid regions in quantities ranging from a trace to many tons per acre-foot. Gypsum is important in the soil as a source of soluble calcium. The use of irrigation waters with a high sodium percentage is less harmful on soils of high gypsum content. The presence of soluble calcium also is important in reclamation processes.

Alkaline-earth carbonates (calcium and magnesium carbonates) usually occur in appreciable amounts in soils in arid areas. These materials may occur as fine salt particles and may improve the physical condition of the soil, or they may occur in hard layers, such as caliche, and restrict water movement. Alkaline-earth carbonates are nearly insoluble and as such have little influence on the sodium (or sodic) status of the soil. These carbonates, however, may be changed to more soluble sulfates by the use of acid-forming soil amendments, such as sulfur or sulfuric acid. The alkaline earth carbonates are, therefore, important in reclamation processes as a potential source of soluble calcium and magnesium, and they often influence the choice of soil amendments.

QUALITY OF IRRIGATION WATER

The quality of irrigation water used has an important influence on the results which may be expected under irrigation. The quality of water is a relative matter, however, rather than a fixed entity, since the results obtained with a given water may be influenced greatly by the crops grown, the soils, climate, management practices and quantity of water available. Nevertheless, water analyses can serve as a valuable guide in estimating the saline or sodic problems which can be expected and for determining management practices best suited for the water at hand.

The quality of irrigation water is influenced by: (1) the total salt concentration or salinity hazard, (2) the amount of sodium and its relation to other cations, (3) the concentration of boron or other constituents that may be toxic and (4) the bicarbonate content in relation to calcium and magnesium.

Salinity Hazard

The salt concentration in most waters is not sufficiently high to be injurious to plant growth.

It is the salt accumulation in the soil which produces injurious saline conditions. As the concentration of salt in the irrigation water increases, the salinity hazard (tendency for salts to accumulate in the soil) likewise increases.

Figure 13 was prepared by the USDA Salinity Laboratory and is a useful guide for estimating the relative salinity and sodic hazard of various waters. The various salinity classes are:

Class 1. *Low-salinity water (C1)* can be used for irrigation with most crops on most soils with little likelihood that soil salinity will develop. Some leaching is required, but this occurs under normal irrigation practices except in soils of extremely low permeability.

Class 2. *Medium-salinity water (C2)* can be used if a moderate amount of leaching occurs. Plants with moderate salt tolerance can be grown in most cases without special practices for salinity control.

Class 3. *High-salinity water (C3)* cannot be used on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required and plants with good salt tolerance should be selected.

Class 4. *Very high salinity water (C4)* is not suitable for irrigation under ordinary conditions, but may be used occasionally under special circumstances. The soils must be permeable, drainage must be adequate, irrigation water must be applied in excess to provide considerable leaching and highly salt-tolerant crops should be selected.

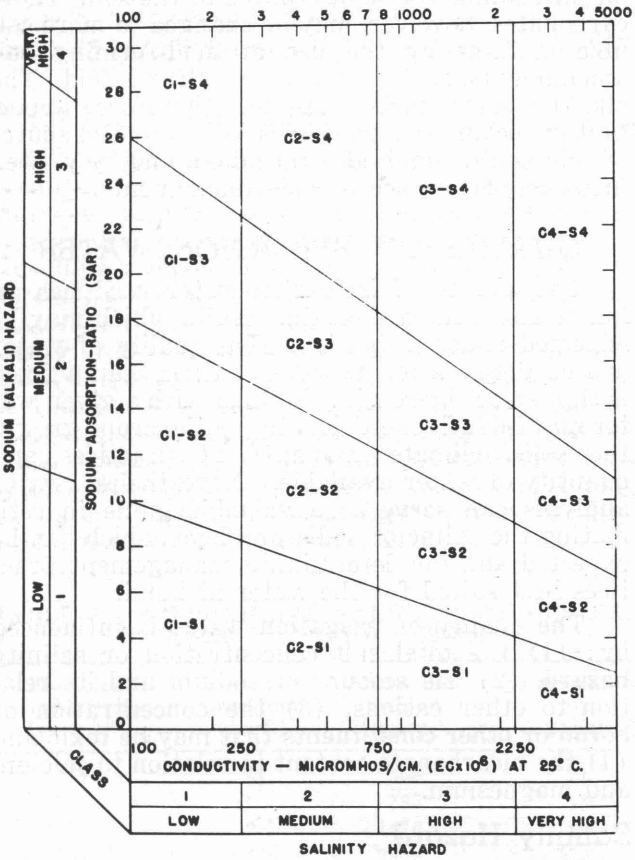

Figure 13. Diagram for the classification of irrigation water. From Handbook 60, U. S. Salinity Laboratory.

Farmers in the Trans-Pecos area of Texas are producing consistently 2 to 3 bales of cotton on upland soil with irrigation water containing approximately 3 tons of salt per acre-foot of water (3500 micromhos/cm.). Soils of the area are rather permeable, underground drainage is good, cotton (salt tolerant) is the principal crop and practices such as furrow planting and frequent irrigation to minimize salinity are customary. Practically all water in the area is classified as Class 4, or very high saline water, according to the guide for salinity classes, Figure 13. To provide a better basis for differentiating between waters within this area, Christensen and Lyerly (2) suggested the following classification: Class I, 0-1 t.a.f.; Class II, 1-2 t.a.f.; Class III, 2-3.5 t.a.f; Class IV, 3.5-5.5 t.a.f; Class V, above 5.5 t.a.f. Other research workers suggested different classifications for other localized areas. Such classifications, which are more lenient than that devised by the U. S. Salinity Laboratory, may be satisfactory for the customary farming practices and areas for which they were designed, *but they should not be extended to other areas or other crops and management practices.*

Sodium Hazard

Since the physical condition of the soil is influenced greatly by an increase in exchangeable sodium, it is necessary to consider the sodium hazard of irrigation water. Also, plants sensitive to sodium may be injured by accumulations of sodium in the soil. Both the sodium adsorption ratio and total salt concentration influence the sodium hazard, as shown in Figure 13.

Low-sodium water (S1) can be used for irrigation on almost all soils with little danger of the development of harmful levels of exchangeable sodium. However, sodium-sensitive crops, such as stone-fruit trees and avocados, may accumulate injurious concentrations of sodium.

Medium-sodium water (S2) will present an appreciable sodium hazard in fine-textured soils having high cation-exchange-capacity, especially under low-leaching conditions, unless gypsum is present in the soil. This water may be used on coarse-textured or organic soils with good permeability.

High-sodium water (S3) may produce harmful levels of exchangeable sodium in most soils and will require special soil management — good drainage, high leaching and organic matter additions. Gypsiferous soils may not develop harmful levels of exchangeable sodium from such waters. Chemical amendments may be required for replacement of exchangeable sodium, except that amendments may not be feasible with waters of very high salinity.

Very high sodium water (S4) generally is unsatisfactory for irrigation purposes except at low and perhaps medium salinity, where the solution of calcium from the soil or use of gypsum or other amendments may make the use of these waters feasible.

Waters with a sodium percentage of less than about 60, and having a low bicarbonate content, are probably satisfactory under most conditions. As the sodium percentage increases above 60 the sodium hazard becomes progressively greater.

The occurrence of appreciable amounts of gypsum in the soil may permit the use of waters having an unfavorably high sodium hazard, particularly if the total salt content of the water is relatively low. The sodium hazard of low saline waters may be reduced by the addition of gypsum to the water. Similarly, it may be advantageous to add soil amendments periodically when using high sodium waters. Only soil amendments containing soluble calcium should be used on noncalcareous soils, while either these or acid-forming amendments, such as sulfur or sulfuric acid, may be used on calcareous soils. The cost of applying a sufficient amount of amendment to correct the sodium hazard of very highly saline water may be prohibitive.

Boron Hazard

While occurring in insignificant amounts in many areas, soluble boron is extremely toxic. Plants sensitive to boron may be injured by as little as 0.7 p.p.m. of boron in the saturation extract, and more than 1.5 p.p.m. appears unsafe except for boron-tolerant plants, Table 5. More water may be required for leaching boron than for other salts. A classification of irrigation water according to the boron concentration is given in Table 7.

Carbonate and Bicarbonate Ions Hazards

As previously indicated, the soil dries after an irrigation and the soil solution becomes more and more concentrated. Under these conditions, there may be a tendency for the less soluble compounds to precipitate from solution. Calcium and magnesium carbonates are much less soluble than sodium carbonate and may precipitate on drying if much is present. The precipitation of calcium and magnesium results in a corresponding increase in the proportion of sodium in solution. The bicarbonate ion is important since it is a source of excess carbonate.

TABLE 7. PERMISSIBLE LIMITS OF BORON FOR SEVERAL CLASSES OF IRRIGATION WATERS[1]

Boron class	Boron-sensitive crops	Semi-tolerant crops	Boron-tolerant crops
	— — — —	Parts per million	— — — —
1 Excellent	<[2]0.33	<0.67	<1.00
2 Good	0.33 to .67	0.67 to 1.33	1.00 to 2.00
3 Permissible	.67 to 1.00	1.33 to 2.00	2.00 to 3.00
4 Doubtful	1.00 to 1.25	2.00 to 2.50	3.00 to 3.75
5 Unsuitable	>[3]1.25	>2.50	>3.75

Scofield (1936).
Less than.
More than.

The extent to which calcium and magnesium carbonates will precipitate and the conditions favoring precipitation are not clearly understood. Waters containing 1.25 - 2.5 meq./l of residual sodium carbonate are probably marginal and those with more than 2.5 meq./l probably are unsafe for irrigation. Therefore, waters with a "possible" sodium percentage much higher than actual sodium percentage possess an additional sodium hazard.

As with high sodium waters, the effects of unfavorably high bicarbonate may be lessened if proper soil amendments are used or if the soil contains an appreciable amount of gypsum.

RECLAMATION

Leaching of undesirable salts is the key to successful improvement and reclamation of salty soils. If an adequate supply of reasonably good irrigation water is available, if soil permeability is reasonably good and if drainage is adequate, it should be possible to reclaim almost any salt-affected soil.

The first step in a reclamation operation should be the collection and analyses or representative water and soil samples. These analyses will provide information as to the severity of the problem and whether the problem involves salinity, sodium or boron, or a combination of these factors. Reclamation procedures should be planned accordingly.

Saline Soils

The reclamation of most saline soils is a relatively simple operation if drainage is not restricted. Sufficient water is passed through the soil to dissolve the excess salts and carry them away in the drainage water. The quantity of water needed for reclamation depends on the amount of salt in the irrigation water and in the soil, and also on the extent of reclamation desired. Three to 4 acre-feet of water, or even more, may be required. The land should be leveled carefully and borders thrown up so that the field can be flooded. Water should be held on the surface until leaching has reduced the salt concentration to a safe level. On slowly permeable soils, it may be desirable to obtain a partial reclamation, then plant a salt-tolerant crop, such as Bermudagrass or barley, to assist in opening up the soil before further leaching. Ordinarily, saline soils are in reasonably good tilth after reclamation and may be farmed at once.

Saline-Sodic and Nonsaline-Sodic Soils

The reclaiming of sodic soils is more difficult than for saline soils, since the former includes replacing exchangeable sodium with calcium and improving soil tilth as well as the leaching of undesired salts. The calcium needed for replacing exchangeable sodium may be supplied in the irri-

TABLE 8. APPROXIMATE AMOUNTS OF GYPSUM AND SULFUR REQUIRED TO REPLACE INDICATED AMOUNTS OF EXCHANGEABLE SODIUM[1]

Exchangeable sodium (meq. per 100 gm. of soil)	Gypsum ($CaSO_4 \cdot 2H_2O$)	Sulfur
	- - Tons per acre-foot of soil[2] - -	
1	1.7	0.32
2	3.4	0.64
3	5.2	0.96
4	6.9	1.28
5	8.6	1.60
6	10.3	1.92
7	12.0	2.24
8	13.7	2.56
9	15.5	2.88
10	17.2	3.20

[1] From USDA Agricultural Handbook 60, U.S. Salinity Laboratory.

[2] 1 acre-foot of soil weighs approximately 4,000,000 pounds.

gation water or perhaps from gypsum in the soil in some cases. Most likely the use of an appropriate soil amendment will be required.

Soil amendments commonly used may be divided into two types: (1) amendments providing soluble calcium, such as gypsum and calcium chloride, and (2) acid or acid-forming amendments, such as sulfur, sulfuric acid, iron sulfate and aluminum sulfate. Calcium polysulfides (lime-sulfur) are both calcium-supplying and acid-forming, but are perhaps most beneficial in the latter capacity. Applications of limestone may be of considerable value as a source of calcium on acid soils, but are of questionable value on alkaline soils.

Amendments providing soluble calcium are suitable for reclamation of all types of sodic soils. Acid-forming amendments are most useful on soils containing calcium carbonate since they react with the latter to form calcium sulfate. The relative value of the different acid-forming amendments is determined largely by their sulfur content. The choice of amendment depends on whether the soil contains calcium carbonate, the cost and the speed of reaction desired. Calcium chloride provides readily soluble calcium, but is too expensive for common use. Sulfuric acid and iron and aluminum sulfates are amendments which act quickly, while sulfur, which is dependent on microbial activity, acts slowly. Where possible, amendments should be mixed thoroughly with the soil for best results. Amendments which are water-soluble can be applied easily and economically in the irrigation water.

Figure 14. Growing and plowing under highly salt-tolerant crops, such as barley, are beneficial in reclaiming and improving the soil structure on sodic soils.

The quantity of soil amendment needed depends on the water quality, quantity of exchangeable sodium to be replaced, completeness of chemical reactions in the soil and other factors. The amounts of gypsum and sulfur required to replace various amounts of exchangeable sodium are given in Table 8. Somewhat higher rates than those shown are suggested, since the replacement process is not complete.

Fields should be bordered and leached by flooding, as with saline soils. Ordinarily, nonsaline-sodic soils have low permeability, and leaching may be slow, often requiring weeks or months. The dispersed condition and poor tilth characteristic of sodic soils may persist after leaching is completed. Farming practices which will improve the soil structure should be used, Figure 14. The soil should not be worked when excessively wet, tillage operations should be kept to a minimum and soil-improving crops should be grown.

Slick Spots

Irrigated fields often contain small irregular areas known as "slick spots." These areas produce little or no growth, are hard and tight when dry and sticky when wet. These usually are small areas of sodic soil. These areas are difficult to reclaim because they cannot be leached without interfering with other operations in the field. A good treatment is to apply and work in a liberal supply of the appropriate soil amendment. Applications of manure or other organic materials, or planting salt-tolerant crops, such as barley or Bermudagrass, are useful for increasing permeability so that leaching may be obtained. Occasionally these slick spots are underlain by localized clay lenses or other impervious layers which impede leaching. Subsoiling, deep plowing and establishment of deep-rooted crops may be beneficial in such cases.

Digging holes through a deep, impervious layer and filling with sand is an expensive process, but often the only satisfactory way in which drainage can be established. This procedure often can be used advantageously for shade trees and ornamental plants.

ACKNOWLEDGMENTS

Much of the information in this bulletin is based on research done at the U. S. Salinity Laboratory, Riverside, California, and also on the findings of other research workers in this and

other states. Reference is not made in the text to all quoted material and references. A more technical and complete discussion of material presented is given in U. S. Department of Agriculture Handbook 60 and other references cited.

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APPENDIX

Definitions

ALKALI SOIL: See sodic soil.

ALKALINE: A chemical term referring to a basic reaction where the pH is above 7.0 as distinguished from an acid reaction where the pH is below 7.0.

ALKALINE-EARTH CARBONATES: Generally refers to calcium and magnesium carbonates, also referred to as lime carbonates.

AVAILABLE WATER (MOISTURE): The quantity of water retained in the soil between the limits of field capacity and the permanent wilting percentage is termed "available water" for plant use. It usually is expressed in inches per foot of soil depth.

ELECTRICAL CONDUCTIVITY (ec): Electrical conductivity provides a rapid, useful measure of salt concentration in water solutions since the amount of current which the solution will conduct is closely correlated with the amount of dissolved salt. The standard unit of conductivity is mhos/cm, however, other units often are used. A water containing approximately 1 ton of salt per acre-foot may be expressed in the following units:

ec — .001148 mhos/cm
ec x 10^3 — 1.148 millimhos/cm or mmho/cm
ec x 10^6 — 1148 micromhos/cm or μ mho/cm

EQUIVALENT: A term developed by chemists to express the unit weight of an element or ion that will react with or be equal to another in chemical reactions. Eight units (grams) of oxygen are used as a standard for comparison. The equivalent weights of chemical constituents receiving primary attention in irrigation are:

CONSTITUENT	CHEMICAL SYMBOL	EQUIVALENT WEIGHT, GRAMS
Calcium	Ca	20.04
Magnesium	Mg	12.16
Sodium	Na	23.00
Potassium	K	39.10
Chloride	Cl	35.46
Carbonate	CO_3	30.01
Bicarbonate	HCO_3	61.02
Sulfate	SO_4	48.03
Gypsum	$Ca\,SO_4 \cdot 2H_2O$	86.05
Sulfur	S	16.03
Sulfuric acid	H_2SO_4	49.04
Iron sulfate	$FeSO_4 \cdot 7H_2O$	139.01

FIELD CAPACITY: Amount of water remaining in the soil after gravitational water has drained downward following irrigation or period of considerable rain. Expressed as inches per foot of soil depth or percentage of soil weight.

ION: Upon dissolving, salts dissociate into particles carrying positive (cations) and negative (anions) electrical charges. These charged particles are called ions.

MILLIEQUIVALENTS PER LITER (meq/l): The milliequivalents of any salt or ion per liter of solution. A milliequivalent = equivalent/1000.

NONSALINE-SODIC SOIL: A soil that contains sufficient exchangeable sodium to interfere with the growth of most crop plants and does not contain appreciable quantities of soluble salt. Quantitively defined as a soil with an exchangeable sodium percentage greater than 15 and a saturation extract conductivity of less than 4 mmhos/cm at 25° C.

OSMOTIC PRESSURE: A property of a solution dependent on the concentration of salts or dissolved substances in the solution (and other factors) and relating to its diffusing tendency. In plant-soil relations, two osmotic pressures are involved. If the osmotic pressure of the root cell sap is higher than that of the soil solution, water will move from the soil into the plant. The more nearly equal the osmotic pressures of the cell sap and soil solution become, the more difficult it is for plants to obtain water. (For a more accurate definition refer to text books on plant physiology or soil physics.)

PARTS PER MILLION (p.p.m.): The parts of salt or salt constituent per million parts of solution.

PERMANENT WILTING POINT: Quantity of water remaining in the soil after plants have withdrawn all they can and wilt permanently. Expressed in inches per foot of soil depth or percentage of soil weight.

RESIDUAL SODIUM CARBONATE: See page 12.

SALINE-SODIC SOIL: A soil containing both sufficient soluble salt and exchangeable sodium to interfere with growth of most plants. Quantitatively defined as a soil containing an exchangeable sodium percentage above 15 with a saturation extract conductivity of 4 mmhos/cm or more at 25° C.

SALINE SOIL: Soil that contains sufficient soluble salt to interfere with the growth of most crop plants. For the purpose of definition, soil for which the conductivity of the saturation extract is 4 or more millimhos per cm. at 25° C.

SALT-AFFECTED SOIL: A soil that contains either sufficient soluble salt or exchangeable sodium, or both, to interfere with the growth of most plants.

SODIC SOIL: A soil containing sufficient exchangeable sodium to interfere with the growth of most crop plants. Quantitatively defined as a soil with an exchangeable sodium percentage greater than 15. Either with or without appreciable amounts of soluble salt. Also known as alkali soil.

SODIUM ADSORPTION RATIO: See page 12.

SODIUM PERCENTAGE: See page 12.

SODIUM PERCENTAGE POSSIBLE: See page 12.

SOIL STRUCTURE: Refers to the manner in which the soil particles are clustered together into clumps or aggregates. A stable structure is highly desirable in the finer-textured soils, since it permits ready penetration of water and air. Green manures and cover crops are especially valuable for their ability to promote aggregation.

SOIL TEXTURE: Refers to the size of the individual particles of which the soil is composed, such as sand, silt and clay. Coarse-textured soils contain large quantities of sand-size particles; fine-textured soils contain considerable clay. Loam is a term indicating that a soil contains appreciable amounts of all three size fractions.

ABBREVIATIONS

t.a.f. = tons per acre-foot
p.p.m. = parts per million
gm. = grams
gr. = grains
c.f.s. = cubic feet per second
g.m. = gallons per minute
meq./l = milliequivalents per liter
sar. = sodium adsorption ratio
t.d.s. = total dissolved solids, generally salts
< = less than
> = more than
esp. = exchangeable sodium percentage
lr = leaching requirement
ec = electrical conductivity
ssp = soluble sodium percentage

FORMULAS FOR CALCULATING WATER DEPTH, VOLUME AND IRRIGATING TIME. THESE FORMULAS DO NOT TAKE INTO CONSIDERATION DITCH LOSS, LOSS OF TAIL WATER OR UNEVEN WATER PENETRATION. ALLOWANCE MUST BE MADE FOR SUCH FACTORS WHERE PERTINENT.

1. Acre-inches per acre $= \frac{\text{cubic feet per second x hours}}{\text{acres x 1.008}}$ or $\frac{\text{gallons per minute x hours}}{\text{acres x 452.5}}$
2. Acre-feet per acre $= \frac{\text{cubic feet per second x hours}}{\text{acres x 12.1}}$ or $\frac{\text{gallons per minute x hours}}{\text{acres x 5430}}$
3. Acre-inches $= \frac{\text{cubic feet per second x hours}}{\text{1.008}}$ or $\frac{\text{gallons per minute x hours}}{\text{452.5}}$
4. Acre-feet $= \frac{\text{cubic feet per second x hours}}{\text{12.1}}$ or $\frac{\text{gallons per minute x hours}}{\text{5,430}}$
5. Hours irrigating time $= \frac{\text{total acre-feet required x 12.1}}{\text{cubic feet per second}}$ or $\frac{\text{acre-feet required x 5430}}{\text{gallons per minute}}$
6. Hours irrigating time $= \frac{\text{acre-inches per acre desired x acres x 1.008}}{\text{cubic feet per second}}$

or

$$\frac{\text{acre-inches per acre desired x acres x 452.5}}{\text{gallons per minute}}$$

EXAMPLE

(1) How many acre-feet of water are pumped per day by a well producing 2,000 gallons per minute?

Use formula 4b $\frac{\text{gallons per minute x hours}}{\text{5,430}} = \frac{\text{2,000 x 24}}{\text{5,430}} = \frac{\text{48,000}}{\text{5,430}} = \text{8.84 acre-feet}$

(2) How many hours will be required to apply 4 inches of water to 100 acres of land when using 5 cubic feet of water per second?

Use formula 6a $\frac{\text{acre-inches per acre desired x acres x 1.008}}{\text{cubic feet per second}} = \frac{\text{4 x 100 x 1.008}}{5} = \frac{403.2}{5} = \text{80.6 hours}$

FACTORS AND CONVERSION FORMULAS[1]

1 cubic foot = 7.48 gallons.

1 gallon = .1337 cubic foot.

1 liter = 1.057 quarts = .2642 gallon

Water weighs: 8.34 pounds per gallon
62.43 pounds per cubic foot
2,719,450 pounds per acre-foot.

Soil weighs: 68 to 100 pounds per cubic foot
4,000,000 pounds per acre-foot (average figure)

One acre-foot of water contains: 43,560 cubic feet
325,829 gallons
12 acre-inches

1 acre-inch of water: weighs 226,620 pounds
contains 27,152 gallons
contains 3,630 cubic feet.

1 million gallons = 3.0689 acre-feet
contains 133,680 cubic feet.

1 percent = 1/100 = 10,000 p.p.m.

10,000 p.p.m. = 1%.

Meq./l x equivalent weight = p.p.m.

Grains per gallon x 17.1 = p.p.m.

p.p.m. x .00136 = tons per acre-foot of water.

ec x 10^3 (millimhos/cm) x 1000 = ec x 10^6 (micromhos/cm).

Tons of salt per acre-foot (t.a.f.) of water x 735 = p.p.m.

1 cubic foot per second = 7.48 gal./sec.
448.8 gal./min.
26,928 gal./hour
646,272 gal./day
60 cu. ft./min.
3600 cu. ft./hour
86,400 cu. ft./day
0.992 acre-inches/hour
23.8 acre-inches/day
0.0826 acre-ft./hour
1.98 acre-ft./day

1000 gallons per minute = 60,000 gal./hour
1,440,000 gal./day
2.228 cu. ft./second
133.68 cu. ft./minute
8021 cu. ft./hour
192,504 cu. ft./day
2.21 acre-inches/hour
53.03 acre-inches/day
0.184 acre-ft./hour
4.416 acre-ft./day

[1] Many of the factors given are in approximate figures.

APPROXIMATE WATER-HOLDING CAPACITY OF SOILS

Soil texture	Moisture held at field capacity[1]	Moisture held at permanent wilting point[1]	Moisture available to plants[1]	Approximate inches of water to wet 3 feet of soil[2]
Sands	1.0 - 1.4	.2 - .4	.8 - 1.0	2.1
Sandy loams	1.9 - 2.3	.6 - .8	1.3 - 1.5	3.2
Loams	2.5 - 2.9	.9 - 1.1	1.6 - 1.8	3.8
Silt loams	2.7 - 3.1	1.0 - 1.2	1.7 - 1.9	4.1
Clay loams	3.0 - 3.4	1.1 - 1.3	1.9 - 2.1	4.5
Clays	3.5 - 3.9	1.5 - 1.7	2.0 - 2.2	4.8

[1] Expressed as inches of water per foot of soil.

[2] Assuming three-fourths of the available water has been evaporated or used by plants at time of irrigation.

TABLE FOR THE REDUCTION OF SECOND-FEET TO ACRE-FEET

Rate of flow, second-feet	Hours																
	.25	.5	.75	1	2	3	4	5	6	7	8	9	10	11	12	24 1 day	168 1 week	720 30 days
.1	.0021	.0041	.0062	.0083	.0165	.0248	.0331	.0413	.0496	.0578	.0661	.0744	.0826	.0909	.0992	.1983	1.388	5.950
.25	.0052	.0103	.0155	.0207	.0413	.0620	.0826	.1033	.1240	.1446	.1653	.1859	.2066	.2273	.2479	.4959	3.471	14.88
.5	.0103	.0207	.0310	.0413	.0826	.1240	.1653	.2066	.2479	.2893	.3306	.3719	.4132	.4545	.4959	.9917	6.942	29.75
.75	.0155	.0310	.0465	.0620	.1240	.1859	.2479	.3099	.3719	.4339	.4959	.5578	.6198	.6818	.7438	1.488	10.41	44.63
1	.0207	.0413	.0620	.0826	.1653	.2479	.3306	.4132	.4959	.5785	.6612	.7438	.8264	.9091	.9917	1.983	13.88	59.50
2	.0413	.0826	.1240	.1653	.3306	.4959	.6612	.8264	.9917	1.157	1.322	1.488	1.653	1.818	1.983	3.967	27.77	119.0
3	.0620	.1240	.1859	.2479	.4959	.7438	.9917	1.240	1.488	1.735	1.983	2.231	2.479	2.727	2.975	5.950	41.65	178.5
4	.0826	.1653	.2479	.3305	.6612	.9917	1.322	1.653	1.983	2.314	2.645	2.975	3.306	3.636	3.967	7.934	55.54	238.0
5	.1033	.2066	.3099	.4132	.8264	1.240	1.653	2.066	2.479	2.893	3.306	3.719	4.132	4.545	4.959	9.917	69.42	297.5
6	.1240	.2479	.3719	.4959	.9917	1.488	1.983	2.479	2.975	3.471	3.967	4.463	4.959	5.454	5.950	11.90	83.30	357.0
7	.1446	.2893	.4339	.5785	1.157	1.735	2.314	2.893	3.471	4.050	4.628	5.207	5.785	.6364	6.942	13.88	97.19	416.5
8	.1653	.3306	.4959	.6611	1.322	1.983	2.645	3.306	3.967	4.628	5.289	5.950	6.612	7.273	7.934	15.87	111.1	476.0
9	.1859	.3719	.5578	.7438	1.488	2.231	2.975	3.719	4.463	5.207	5.950	6.694	7.438	8.182	8.925	17.85	124.9	535.5
10	.2066	.4132	.6198	.8264	1.653	2.479	3.306	4.132	4.959	5.785	6.612	7.438	8.264	9.091	9.917	19.83	138.8	595.0
11	.2273	.4545	.6818	.9091	1.818	2.727	3.636	4.545	5.454	6.364	7.273	8.182	9.091	10.00	10.91	21.82	152.7	654.5
12	.2479	.4959	.7438	.9917	1.983	2.975	3.967	4.959	5.950	6.942	7.934	8.926	9.917	10.91	11.90	23.80	166.6	714.0
13	.2685	.5372	.8058	1.074	2.149	3.223	4.297	5.372	6.446	7.521	8.595	9.669	10.74	11.82	12.89	25.78	180.4	773.5
14	.2892	.5785	.8678	1.157	2.314	3.471	4.628	5.785	6.942	8.099	9.256	10.41	11.57	12.73	13.88	27.77	194.3	833.0
15	.3099	.6198	.9297	1.240	2.479	3.719	4.959	6.198	7.438	8.678	9.917	11.15	12.40	13.64	14.88	29.75	208.2	892.5
20	.4132	.8265	1.240	1.653	3.305	4.959	6.612	8.265	9.917	11.57	13.22	14.88	16.53	18.18	19.83	39.67	277.6	1190
25	.5165	1.033	1.550	2.066	4.132	6.198	8.265	10.33	12.40	14.46	16.53	18.59	20.66	22.72	24.79	49.59	347.1	1487
50	1.033	2.066	3.099	4.132	8.265	12.40	16.53	20.66	24.79	28.92	33.05	37.19	41.32	45.45	49.59	99.17	694.2	2975
75	1.550	3.099	4.649	6.198	12.40	18.59	24.79	30.99	37.19	43.39	49.59	55.78	61.98	68.18	74.38	148.8	1041	4462
100	2.066	4.132	6.198	8.264	16.53	24.79	33.06	41.32	49.59	57.85	66.11	74.38	82.64	90.91	99.17	198.3	1388	5950

TABLE FOR THE REDUCTION OF GALLONS PER MINUTE TO ACRE-INCHES

Gallons per minute	Hours																
	.25	.5	.75	1	2	3	4	5	6	7	8	9	10	11	12	24 1 day	168 1 week	720 30 days
1	.0006	.0011	.0017	.0022	.0044	.0066	.0088	.0111	.0133	.0155	.0177	.0199	.0221	.0243	.0265	.0530	.3713	1.591
5	.0028	.0055	.0083	.0110	.0221	.0331	.0442	.0552	.0663	.0773	.0884	.0994	.1105	.1215	.1326	.2652	1.856	7.955
10	.0055	.0110	.0166	.0221	.0442	.0663	.0884	.1105	.1326	.1547	.1768	.1989	.2210	.2431	.2652	.5304	3.712	15.91
20	.0110	.0221	.0331	.0442	.0884	.1326	.1768	.2210	.2652	.3094	.3536	.3978	.4420	.4862	.5304	1.061	7.425	31.82
30	.0166	.0331	.0497	.0663	.1326	.1989	.2652	.3315	.3978	.4641	.5303	.5966	.6629	.7292	.7955	1.591	11.14	47.73
40	.0221	.0442	.0663	.0884	.1768	.2652	.3536	.4420	.5303	.6187	.7071	.7955	.8839	.9723	1.061	2.121	14.85	63.64
50	.0276	.0552	.0829	.1105	.2210	.3315	.4420	.5524	.6629	.7734	.8839	.9944	1.105	1.215	1.325	2.652	18.56	79.55
60	.0331	.0663	.0994	.1325	.2652	.3978	.5303	.6629	.7955	.9281	1.061	1.194	1.325	1.458	1.591	3.182	22.74	95.46
70	.0387	.0773	.1160	.1547	.3094	.4641	.6187	.7734	.9281	1.083	1.237	1.392	1.547	1.701	1.856	3.712	25.99	111.4
80	.0442	.0884	.1326	.1768	.3536	.5303	.7071	.8839	1.061	1.237	1.414	1.591	1.768	1.945	2.121	4.243	29.70	127.3
90	.0497	.0994	.1492	.1988	.3978	.5966	.7955	.9944	1.194	1.392	1.591	1.790	1.989	2.188	2.387	4.773	33.41	143.2
100	.0552	.1105	.1657	.2210	.4420	.6629	.8839	1.105	1.326	1.547	1.768	1.989	2.210	2.431	2.652	5.303	37.12	159.1
250	.1381	.2762	.4143	.5524	1.105	1.657	2.210	2.762	3.315	3.867	4.420	4.972	5.524	6.077	6.629	13.25	92.81	397.8
500	.2762	.5524	.8287	1.105	2.210	3.315	4.420	5.524	6.629	7.734	8.839	9.944	11.05	12.15	13.25	26.52	185.6	795.5
750	.4143	.8287	1.243	1.657	3.315	4.972	6.629	8.287	9.944	11.60	13.25	14.92	16.57	18.23	19.89	39.78	278.4	1193
1000	.5524	1.105	1.657	2.210	4.420	6.629	8.839	11.05	13.25	15.47	17.68	19.88	22.10	24.31	26.52	53.03	371.2	1591
1250	.6906	1.381	2.072	2.762	5.524	8.287	11.05	13.81	16.57	19.33	22.10	24.86	27.62	30.38	33.15	66.29	464.0	1988
1500	.8287	1.657	2.486	3.315	6.629	9.944	13.25	16.57	19.89	23.20	26.52	29.83	33.14	36.46	39.78	79.55	556.9	2386
1750	.9668	1.934	2.900	3.867	7.734	11.60	15.47	19.33	23.20	27.07	30.94	34.80	38.67	42.54	46.40	92.81	649.7	2784
2000	1.105	2.210	3.315	4.419	8.839	13.25	17.68	22.10	26.52	30.94	35.35	39.78	44.19	48.61	53.03	106.1	742.4	3182
2250	1.243	2.486	3.729	4.972	9.944	14.92	19.88	24.86	29.83	34.80	39.78	44.75	49.72	54.69	59.66	119.3	835.3	3579
2500	1.381	2.762	4.143	5.524	11.04	16.57	22.10	27.62	33.15	38.67	44.19	49.72	55.24	60.77	66.29	132.5	928.1	3977
3000	1.657	3.314	4.972	6.629	13.25	19.89	26.52	33.15	39.78	46.40	53.03	59.66	66.29	72.92	79.55	159.1	1113	4773
5000	2.762	5.524	8.287	11.05	22.10	33.15	44.19	55.24	66.29	77.34	88.39	99.44	110.5	121.5	132.5	265.2	1856	7955