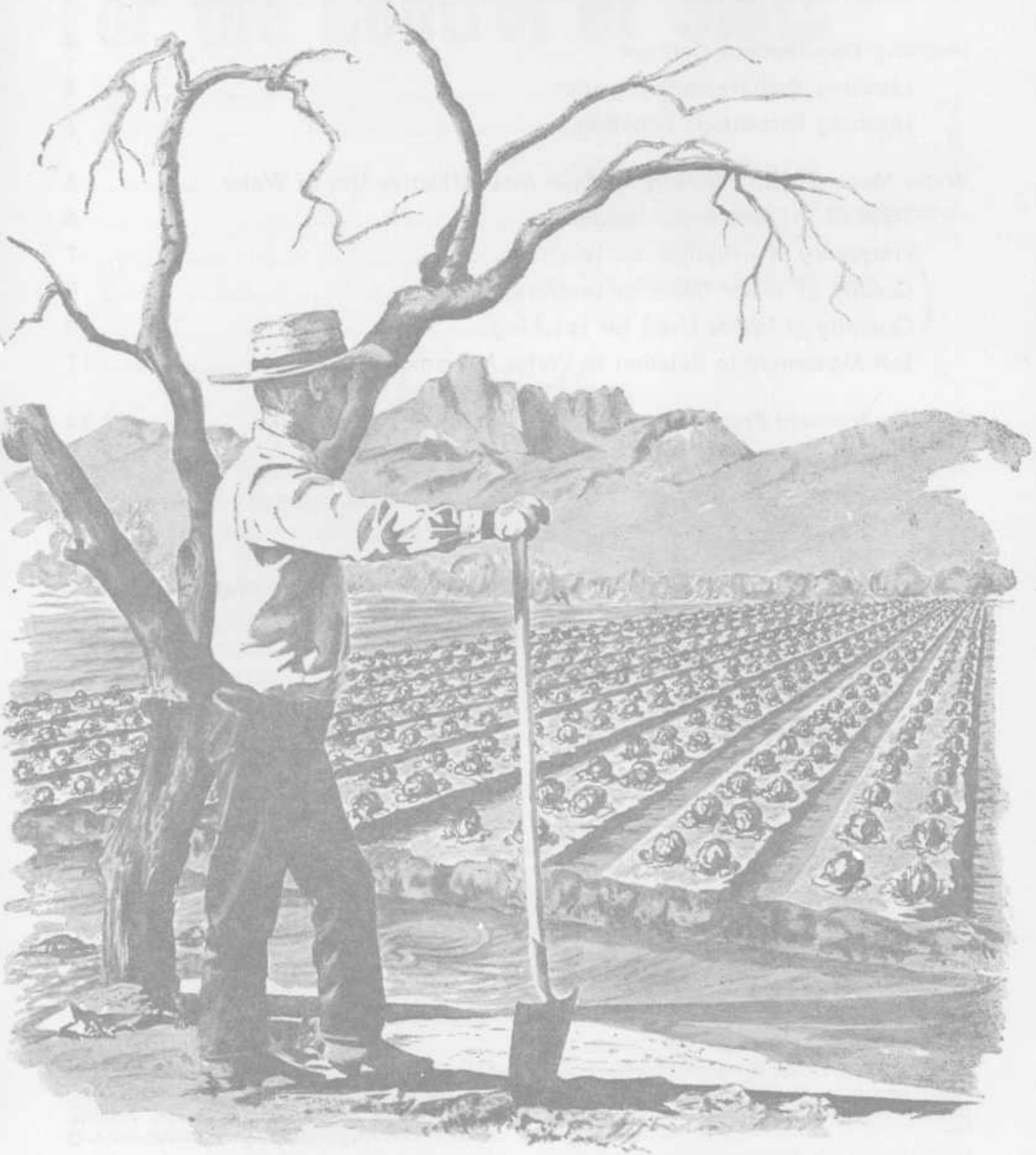
Water, Soil, and Crop Management Principles For the Control of Salts



Bulletin A-43

The University of Arizona
Agricultural Experiment Station & Cooperative Extension Service

Table of Contents

Issued in furtherance of cooperative extension work in agriculture and home economics, Acts of May 8 and June 30, 1914, in cooperation with the U. S. Department of Agriculture. George E. Hull, Director of Extension Service, The University of Arizona College of Agriculture, Tucson, Arizona.

4M—Reprinted July 1967—Bulletin A-43

Water, Soil, and Crop Management Principles For the Control of Salts

By

WALLACE H. FULLER

Head, Department of Agricultural Chemistry and Soils

The University of Arizona

Introduction

Permanent agriculture in arid and semiarid climatic conditions is dependent upon the control of salts in soils. The main sources of salts that may accumulate or concentrate in undesirable amounts within the root zone of crops are:

(a) In the irrigation water;

(b) Native in the soil.

Different crops vary markedly in their ability to grow in the presence of soluable salts in the soil solution that bathes their roots. Control of salts for economic agricultural production, therefore, will depend on the **way the water, soil, and crops are managed.**

Water

Continued addition of irrigation water to the soil will add salts. Salts eventually will accumulate sufficiently to reduce plant growth and crop yields. Finally, they may prevent a crop from growing altogether, unless irrigation practices are followed which move salts downward below the root zone.

Water is needed, consequently, not only to grow crops but to dispose of salts.

Soil

Adverse effects on plants can be complicated further by improper soil management practices resulting in the movement of soluble soil salts **upward** by capillarity. The concentration of salt on or near the soil surface, well within the effective root zone of growing crops, can seriously affect productivity.

Accumulation of salts at harmful levels of concentration, however, can appear anywhere within the root zone with no visible indication of their location. Unless samples of soil are taken at various depths in the soil profile for chemical analyses, accumulations will remain unnoticed until crop production is seriously affected or crop failure occurs.

Effective methods are available to detect the level of soluble salt concentrations at different depths in the soil. Studies on salt accumulations in soil profiles reveal that the level of salt at different depths in most irrigated soils is quite variable. Variability is most pronounced in alluvial soils where soil textures change abruptly or where compaction causes changes in rate of water movement.

Crop

Economic crop production in arid and semiarid climates must also take into consideration sound crop management practices. Plants differ markedly in their ability to grow and produce under saline conditions.

Thus, the grower should have a good knowledge of certain factors in his development of management practices, such as:

(a) The salt-tolerance levels of different crops
(b) The placement of seed to avoid high-salt spots
(c) Rotation of crops
(d) Stand establishment
(e) The effect of the osmotic tension factor of the solution bathing the roots.

All are vitally important to the establishment of a permanent agriculture.

Purpose

This bulletin is concerned primarily with basic principles in water, soil, and crop management of irrigated lands in arid and semiarid climates to prevent accumulation of harmful levels of salt. It also presents concepts of management as related to long-time irrigation and leaching of soils necessary to maintain permanent agriculture. It is not intended to consider the reclamation of soils, although some principles described will apply to leaching for reclamation of saline soils.

How Salt Affects Plants

Saline conditions of the soil reduce the productivity and value of the land. Soluble salts affect plants in several ways:

(a) Reduce moisture availability;
(b) Alter nutrient availability;
(c) Alter physical condition of the soil limiting root penetration;
(d) Cause direct toxicity.

The most common effect of high salts is to raise the osmotic pressure of the soil solution, causing physiological scarcity of water in the environment in which the plant grows. Only a few salts found in soils appear in truly toxic concentrations. The varying physiological response of different plants to saline soils, however, limits generalizations.

Fortunately, the most abundant salts found in soils of arid and semiarid climates are calcium — primarily calcium sulfate (gypsum) and calcium carbonate (lime, caliche). Both salts are only slightly soluble and precipitate as solids as they concentrate. Thus they are removed from the possibility of seriously harming arid-land crops.

For example, calcium sulfate in its highest soluble concentration provides only about 2.2 mmhos* of salinity. This concentration is well within the tolerance level of most economic crops.

On the other hand, sodium salts are much more soluble than calcium salts and chlorides are more soluble than sulfates. Thus excessive accumulation of sodium and chloride in soils can produce harmful effects on crops. These are the highly soluble salts that must be continually leached below the root zone of crops.

*See Appendix of Definitions and Symbols at back of bulletin.

Leaching Requirement Concept

The leaching of soils, to keep salts moving downward below the effective root zone of the crop being grown, has long been recognized as a necessary farm operation. Nevertheless, there are growers who still ignore this basic and life-maintaining principle.

Leaching requires that more water be used than is necessary to grow a crop at the salt level intended. A permanent agriculture on irrigated land requires leaching of the soil, since irrigation waters contain salts that would otherwise accumulate. Thus leaching principles have been established as a guide for use in irrigation practices.

Leaching Requirement Equation

In an effort to estimate the leaching necessary for the maintenance of a favorable input-output salt balance of an area, an equation is applied for estimating the "**fraction of irrigation water that must be leached through the root zone to control soil salinity at any specified level.**"

The amount of water used for leaching will depend upon the salt concentration in the irrigation water and the outgoing salt level in the drainage water. An equation has been suggested for calculating the **Leaching Requirement** (LR). It is the ratio of the equivalent depth of drainage water (Ddw) to the depth of irrigation water (Diw):

$$LR = \frac{Ddw}{Diw} = \frac{ECiw}{ECdw},$$

where ECiw and ECdw represent the electrical conductivity of the irrigation and drainage water, respectively.

The highest concentration of the salt in the soil solution, except for the crust, usually occurs at the bottom of the wetting zone. Therefore, the drainage water will contain the maximum concentration of salt.

The Leaching Requirement is basically a good general concept for an understanding of drainage but is definitely limited in its overall application to either a large- or small-scale planning of salinity control in irrigated agriculture.

Leaching Percentage Equation

Many factors, altering the denominator particularly, are believed to enter into the LR equation. Area characteristics will vary; consequently the equation can vary. In practical agricultural production the "Leaching Percentage" appears to be nearer to the actual field needs for leaching. The equation is:

$$LP = \frac{ECiw}{2\ EC_e},$$

at 50 percent yield decrement: Where ECiw and EC_e represent the electrical conductivity of the irrigation water and the saturated-soil-paste extract associated with 50% decrement of crop yield, respectively. (Also see Appendix for calculation.)

Water Management Practices To Make Most Effective Use of Water

Time for Irrigations For Leaching

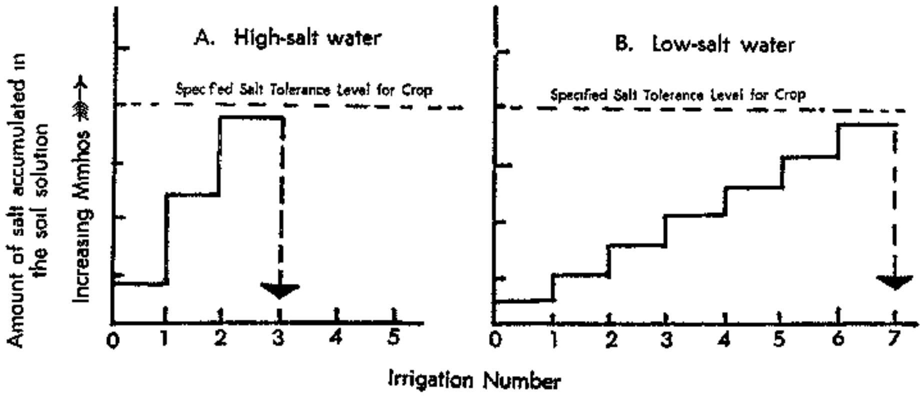
Leaching of salts is best accomplished with a preplant irrigation and again early in the growing season if necessary. Soil moisture for plant use also should be stored deep, early in the season. At this time the soil takes water most rapidly.

As the season progresses most soils take water more slowly. During July and August it may become impractical to completely refill the soil to the depth of the roots. Leaching below the root zone at this late date often is wholly out of the question, both from the standpoint of simple mechanics of moving water through the soil and the well-being of the crop having to withstand long periods of flooding.

The most desirable time to irrigate to leach is when the soil is driest. As the soil dries it shrinks and begins to form cracks and fractures. This process continues as the soil dries further until the soil becomes quite "open" and porous, allowing water to pass through at a much accelerated rate as compared when wet or moist.

Excessive drying and shrinking of some very fine-textured soils, however, may oppose leaching, since water will move through the cracks of the soil so fast that movement of salts from the soil body is poorly accomplished.

It may not be necessary to leach salts below the root zone after each growing season. In fact, it is not necessary to leach until the salt level of the soil solution begins to



Time of Irrigations

approach that of the specified salt tolerance of the crop to be grown.

The time to irrigate a crop is just before it needs water. This is not always the optimum time for leaching because the soil is not dry unless the crop is overstressed for moisture. On the other hand, if the soil takes water well at the time the crop needs water, leaching can be accomplished concurrently with watering of the crop.

It must be kept in mind that if the plant-signs indicate irrigation is overdue, **more** water is required than if irrigation is begun at a time **just before the crop shows water stress.** Stressing of crops for water under saline conditions to the point where visual signs are apparent before watering results in reduction in yield.

The rate of accumulation of salt in the soil is another important factor that affects the time of application of water for leaching. The salts contained in irrigation water used to grow crops must not be allowed to collect in excessive amounts during the growing season. Therefore it may be necessary to leach during the cropping season.

The saltier the water the more frequently the soil requires leaching. Diagrammatically this principle is illustrated above.

In case A, salts should be leached from the soil at the time of the 3rd irrigation. In instance B, leaching need not take place until after the 7th irrigation.

Accumulations of salts nearly to the tolerance level which will cause no more than 50% decrement in maximum potential yield as determined under sand cultural conditions, usually do not seriously affect the economic production of the crop. Beyond this limit, salts will reduce yields seriously and eventually kill the crop unless leaching is practiced at the proper time.

Frequency of Irrigation For Leaching

The frequency of leaching depends upon several factors: (a) quality of water, (b) quantity of water used for irrigation of crop as well as leaching, (c) soil texture, (d) permeability of the soil, (e) depth to a water table, (f) time of the year, (g) salt tolerance of the crop grown, (h) economics.

Quality of water—In general the poorer the quality of the water, with respect to total soluble salts the more frequently the soils must be leached to keep salts washed below the most active root zone.

On the other hand, soils that are high in sodium (alkali) are best managed by leaching more slowly and for longer periods of time to permit the sodium to exchange with calcium and diffuse out into the downward moving soil solution. Thus sodium (sodic) soils are more efficiently leached less frequently but with more water than are saline soils.

Quantity of water — Various equations have been developed to provide a rough estimate of amount to use to compensate for quality. The leaching percentage is one of these equations. It requires that all of the water moves into the soil.

Passing water over the surface of the soil, even where salt crusts are observed, and removing the runoff of water at the end of the field provides no effective control of salts. Such procedure only moves salts into the soil with very little pick up of salt in the surface flow.

Soil texture affects the frequency as well as amount of water to be used. Fine-textured soils, such as clays and silts, require more water than coarse-textured soils such as sands. Also, fine-textured soils usually contain more salts since growers do not always take into account textural differences in relation to water-holding capacity when irrigating.

For example, growers will put 3-acre feet of water on clay as well as sandy soils for growing cotton, not knowing that the same amount of water will not wet all soils to the same depth. In order to get water to a depth of six feet in a sandy soil, it requires 6-9 acre-inches; whereas, in a clay soil it requires 9-13 inches.

Permeability of soil—In general, the less permeable the soil, the longer the water must remain on the field to effect leaching. Thus it could be visualized that the more impermeable the soil the more water is required per single irrigation (or leaching) at less frequent intervals.

Less frequent intervals of leaching would permit the soil to dry out more thoroughly between leachings which would tend to improve the rate of water penetration.

Depth to a water table—If the water table is shallow (only a few feet from the surface) and drainage restricted, the amount of water used for leaching would be less than if the table is deep or not present at all. Shallow water tables would mean more frequent leachings of water of smaller quantities to maintain a favorable soluble salt level in the effective root zone.

Drainage must be adequate for removal and discharge of soluble salts below the root zone of the crops.

Time of the year — Because of great losses of water by evaporation of water from water and soil surfaces during hot weather and the high rate of evapotranspiration by plants, it is much more economical to leach during the cooler time of the year.

The frequency of irrigation of winter crops is reduced during the cool time of the year. Furthermore, water may be more plentiful and drainage conditions more favorable when crops are not on the land during the winter months.

Salt tolerance of the crop—The greater the salt tolerance of the crop the less frequent the necessity for irrigating for leaching. In short, salts may be allowed to build up to greater levels when irrigation is used for the crop alone before the irrigation designated for leaching is undertaken.

The rate of build up of salts in the soil in the root zone will determine the frequency rate of salt leaching.

Intermittent leaching—Intermittent leaching is more effective than continuous leaching, provided the soil is permeable and the water readily wets the soil to a depth below the effective root zone. Intermittent leaching allows the soil to shrink and swell, increasing the cracking and fracturing which accelerates the rate of flow through the soil.

Economics — Many factors enter into the economics of irrigation frequency. Such factors are: **time of delivery, availability of water, nature of the quality of water** at a particular time of the year, **cost of delivery,** and **pattern of delivery** for the project.

Quality of Water Used for Leaching

Amount—In general the higher the salt content of the water used for leaching the greater the amount necessary to use for growing crops. This is not necessarily true for leaching to remove salts from the plant root zone.

Waters of unusually high-salt content such as drainage water, waste effluents, or salty wells offer possibilities of use for leaching. This is particularly applicable in the reclamation of sodic or highly saline soils. High-salt waters act as a flocculent and source of divalent ions.

The extent of use of such poor quality water, however, depends on the total salt content and presence of good quality water for dilution purposes and/or final leaching. High-salt waters are most effective in reclaiming sodic soils.

Kind of Cations — Waters that have a wide ratio of $Na^+/Ca^{++} + Mg^{++}$ are more difficult to manage than those having a narrow ratio. When soils contain gypsum ($CaSO_4 .2H_2O$), the relationship between Na and Ca + Mg is not so critical since the calcium salts in the soil can provide Ca^{++} ions for maintaining a favorable Ca-clay soil.

There is very little danger of developing a "sodic" soil where there is free $CaSO_4 .2H_2O$ and the irrigation water has a ratio of $Na^+/Ca^{++} + Mg^{++}$ of less than 3 to 4 even though the water is salty.

Salt Content of the Soil — The key to the ability to use waters of poor quality for leaching in an irrigation program is the salt content of the soil. As long as the salt content of the soil solution **exceeds** that of the leaching water, salts can be removed from the soil by its use.

One cannot expect, however, to reduce the salt content of the soil solution below the level of the salt content of the leaching water. One might envisage a practice of water conservation whereby the salts are allowed to build up during the growing season or part of the growing season and then leaching at a time just before the specified salt tolerance level of the crop being grown is approached. Poor quality waters may be used for the initial leaching to remove the excess salts and a final leaching with good water being employed—as a means of conserving the good water.

Quantity of Water Used for Leaching

Prevent Excessive Salt Build Up—Irrigation and leaching practices must be designed to prevent the excessive build up of salts which accumulate from salts of added irrigation water. The original leaching requirement equation is given for the depth of irrigation water required to meet **both** the crop needs and leaching percentage.

Any equation established for leaching purposes should not only take into account the level of salt in the soil at the beginning of the leaching practice, but also the salt-level to which the soil must be brought and maintained for growing the specific crop in question.

Leaching Phenomena—Three important phenomena take place during leaching of a soil: (a) As the water saturation front moves downward in the soil, the concentration of salts is always highest at or near the wetting front; (b) Smaller portions of water more frequently employed are more efficient than the same amount of water applied less frequently and in large portions, provided, of course, that all of the leachings are accomplished to a depth below the effective root zone; and (c) A large amount of salt can be carried in a small amount of water.

Furthermore, because of textural differences within the root zone the salt content often varies considerably and is not uniformly distributed.

Precipitation of Salts—As the soil solution becomes more concentrated due to removal of water by plants and loss by evaporation, or for any reason, **the more insoluble salts such as those of calcium and magnesium will tend to precipitate in the soil as slowly** soluble solids. This reduces the effective salt concentration in the soil solution.

Waters that have predominantly calcium and magnesium cations with low sodium and potassium, thus, are usually better waters than their original electrical conductivities indicate. The more soluble salts, such as sodium and potassium and chlorides, move out of the soil more rapidly during leaching than the less soluble salts.

Calculation of Leaching Need: Because of the above principles, the quantity of water necessary to accomplish the desired leaching to bring the salt content of the soil to any **specified level** under practical field conditions is not necessarily proportional to salt content of the irrigation water divided by the salt content of the drainage water as the equation,

$$LR = \frac{ECiw}{ECdw},$$

would imply. This equation in its present form is unrealistic in its application for high-salt water or high-salt soils as has been previously explained.

The **leaching percentage** equation,

$$LP = \frac{ECiw}{2\ EC_e\ 50\%} \times 100,$$

as proposed earlier is much more applicable. The LP is calculated by determining the electrical conductivity of the irrigation water and dividing this by two times the electrical conductivity of the saturated-soil-paste extract designated in the USDA Salinity Laboratory Handbook No. 60 as being the salt tolerance level for a 50% decrement in crop yield; then multiplying by 100 to get percentage.

Salt Movement in Relation To Water Movement

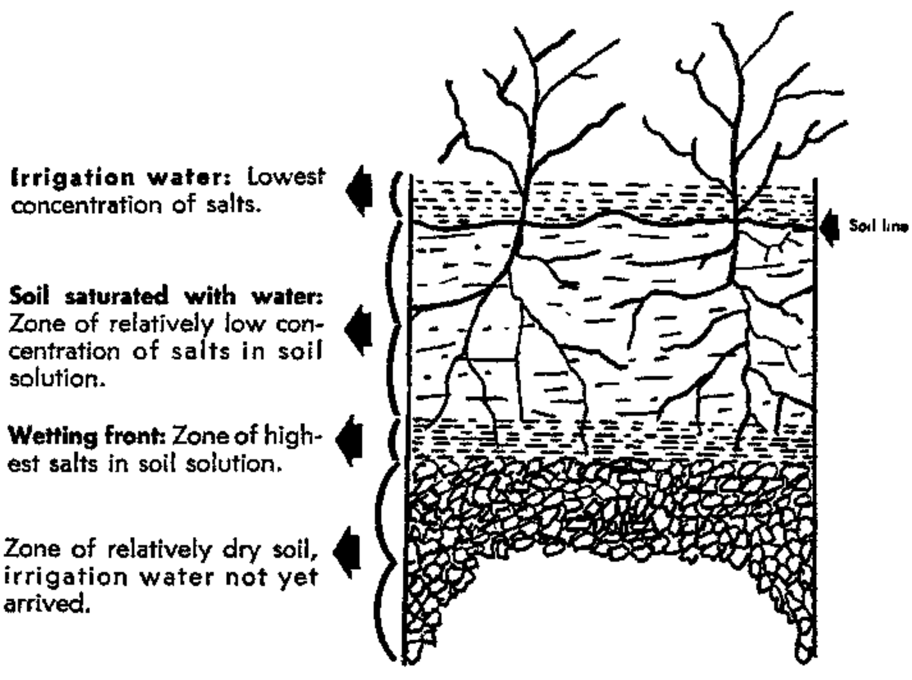
Salts do not move in dry soil. Salts move by dissolving in the water added to the soil and move with the water **in the direction of the flow of water.**

Drying Cycle: During the drying cycle, salts may move **upward** when water is withdrawn by roots and by evaporation at or near the surface. Under these conditions a water deficit will occur near the surface; water will move upward by capillary forces and bring salt from lower depths to the surface. The extent will depend on rate of water loss from the soil surface and internal rate of moisture equilibration with other moisture-moving forces.

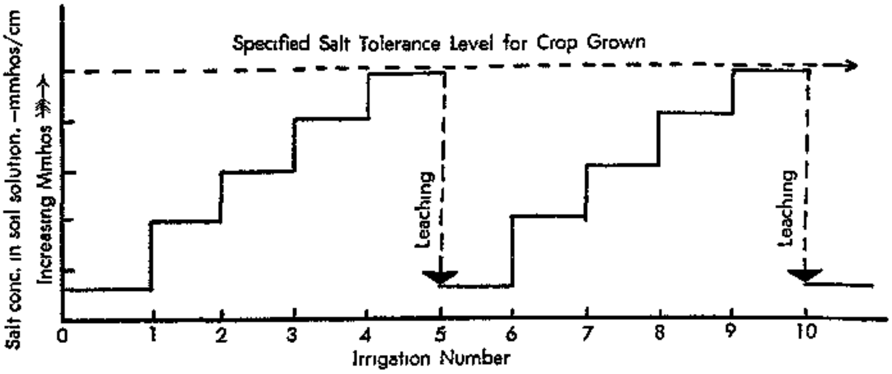
Wetting Cycle: Salts move **downward** when the water flows **downward** by gravitational and capillary forces. **The highest concentration of salts** in the leaching water is found at or near the wetting front.

The diagram below is suggested to illustrate a typical example of salt distribution in the water as it passes through the soil.

Salts will not move beyond the depth of penetration of the water. Therefore, if the quantity of water is sufficient to penetrate the soil to a depth of ½, 1, 2, 3 or 4 feet, or



Salt Distribution in the Water



Leaching of Salt

below the root zone of the growing crop, salts will penetrate to the same depth and accumulate at or near the deepest point of penetration. Because of this principle, the history of the past irrigation practice is readily detected by comparing the soluble salt concentration throughout the soil to a depth representative of the depth of the active root zone of the specified crop.

To illustrate, if there is a zone of soluble salt accumulation at the 1-foot level and the concentration is less below one foot, it indicates the irrigation water probably seldom if at all penetrated much below the 1-foot level. If the zone of highest accumulation of soluble salts occurs at 4 feet, it may be surmised that the quantity of water used was sufficient to wet the soil to 4 feet and leach salts fairly well below the most active root zone of crops.

Pronounced vertical differences in soil texture and soil compaction, however, may obscure the irrigation pattern somewhat.

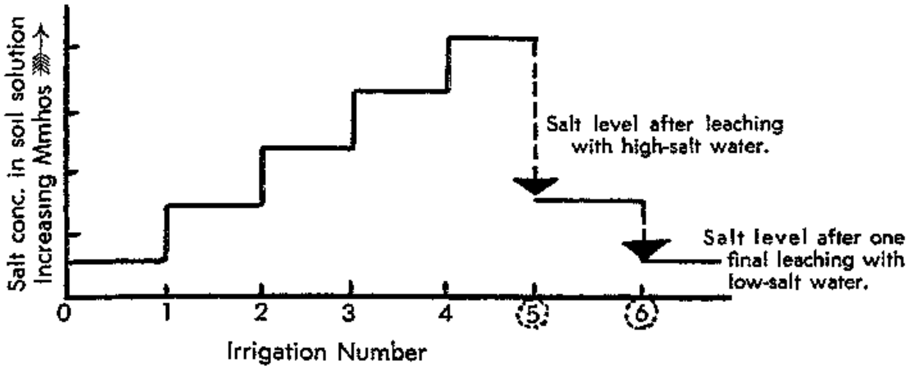
Water can be conserved by leaching the soluble salts below the root zone only occasionally during the growth of the crop, provided, of course, that the salts are not allowed to accumulate beyond the specified tolerance level of the crop.

To illustrate this principle the diagram above is presented.

Thus, irrigations 5 and 10 should be extra heavy to leach the salts below the root zone. Other leachings could be light, but deep enough to provide water throughout the most effective root zone for the consumptive use by the plant and to satisfy the demand of evapotranspiration.

Irrigations 4 and/or 8 could represent preplant and/or postharvest leaching when water was most plentiful or the soil most receptive to leaching.

Intermittent leaching is more effective than continuous leaching, because a little water will carry a lot of salt and because soils that have had an opportunity to dry out



Leaching With Salty Water

somewhat take water more readily.

Often it is advantageous to use salty water for leaching. If the leaching water is less salty than the soil solution, salts can be removed. Better water, then, may be used for the last leaching.

To illustrate this point the diagram above is provided.

It must be made clear, however, that leaching with salty water will not improve the salt level of the soil solution beyond or below the level of the salt in the water used for leaching. If the level of the salt in the soil requires further lowering, better quality water must be used.

Calcium and magnesium cations in the soil solution are adsorbed by the soil exchange complex more strongly than sodium. In fact, at equivalent concentrations in the soil solution, the quantity of calcium and magnesium adsorbed are several times that of sodium.

In the leaching of soils to transport salts down below the root zone, **salty water can be used to initiate the process** and lower the level of salts to a certain value depending on the concentration of the irrigation water. This method has several advantages: (a) The "valence - dilution"* principle is operative; (b) High-salt waters have a high flocculating effect on the soil, permitting more rapid movement of water through the soil than in nonsaline soils; (c) In addition to the divalent cations (CA^{++} and Mg^{++}) supplied by the water, those contained in the soil as gypsum and lime are made more soluble by the presence of monovalent cations such as sodium; (d) the exchange rate of Na^{+} by Ca^{++} or Mg^{++} is greatly accelerated by the increased rate of movement of water through the soil; (e) The sodium in the water can be considered as an "accelerator" in the leaching process.

Other values of the high-salt water leaching method may be: (a) More economical and efficient use of available water supplies; (b) Leaching "off season" when waters of different qualities are available; (c) Extension of all available sources of water; and (d) More effective use of the district's water distribution system and labor.

*Valence-dilution principle involves the exchange of divalent cations (Ca^{++} and Mg^{++}) from the water for absorbed monovalent cation, sodium (Na^{+}).

Soil Management Practices To Make Most Effective Use of Water

Arid and semiarid soils, particularly, require special attention to soil management practices if adverse accumulation of salts are to be avoided. This is especially important where there is poor quality of water and where the quality is variable. Low production or even crop failure can result from the failure to recognize that arid and semiarid irrigated soils require special soil management practices.

Tillage to Improve Water Penetration

Deep tillage — Where soils vary in texture — such as are usually found in alluvial areas near rivers and streams — deep plowing, ripping, knifing, and sweeps or other tilling to eliminate or disrupt horizontal zonations of soil of different textures markedly improves the rate of water penetration through the soil. The reason for this is that, regardless of the succession of textural changes; i.e., sand to silt or silt to sand, water will collect or perch at the junction of the textural change, thus slowing considerably the rate of flow of water.

Futhermore, clay lenses which are found commonly, even though they are very thin layers, will impede water penetration and should be disrupted. If the downward flow is interrupted by a layer of very low water conductivity, then the hydraulic gradient may approach zero just above the boundary between the two layers as the soil pores become filled with water and the condition of static equilibrium under gravity is approached.

Minimum tillage—Minimum tillage should be practiced on irrigated land to avoid serious soil compaction problems and impairment of internal water movement.

The principles involved are simply:

(a) To avoid unnecessary traffic over the land;
(b) To till as infrequently as possible;
(c) To maintain as coarse soil particles as possible.

Often minimum tillage requires ripping, knifing, deep mulching (vertical mulching), or deep plowing to disrupt or break up hardpans.

The purpose of minimizing soil compaction is three fold:

(a) Maintain good water penetration — Compact soil impedes downward water flow.
(b) Insure good root penetration — Roots penetrate compact soil layers with difficulty if at all. This reduces the root feeding area with consequent reduction in yield and efficiency of water utilization.
(c) Prevent salt accumulation — Salts tend to accumulate in compact layers which further make the layer progressively more compact and resistant to root penetration.

Salts are leached from compact layers only with difficulty. Chemical treatments and/or additives are of no value in correcting soil compactions due to mechanical particle-distribution patterns. Only by mechanical implementation can these compact layers be minimized.

Soil moisture and tillage — Deep tillage is most effectively accomplished when the soil is dry. The drier the soil, the greater will be the shattering and cracking effect.

When the soils are again irrigated, water will move further and at a faster rate if the soils have been rough tilled when dry. Moreover, the residual pore space will be greater after wetting than if the soil were worked when wet.

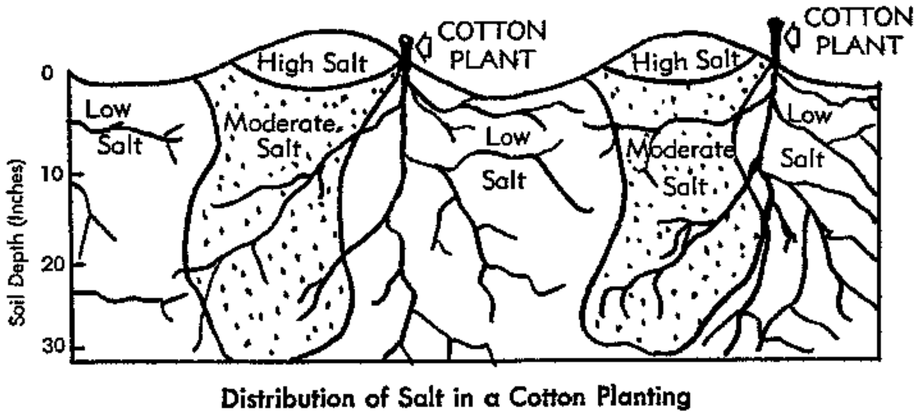
Working the surface soil excessively when dry, into a dry powder, should be avoided.

Land leveling, seedbed preparation and bed shape—The most critical stage of a plant to salinity is during the germination and seedling stage. Every effort must be taken to avoid concentration of salt near the plant at this time.

Irregular leveling of land that leaves high and low spots, even though only a slight change in elevation, results in accumulation of salts in the high spots and in ridges. With the furrow and corrugated method of land preparation, water moves downward and outward from the furrow and upward into the ridges. The latter carries salts into these ridges where it concentrates.

Another example of salt concentrating in ridges is in row crops. Salts concentrate in cotton ridges in a manner similar in pattern to the diagram below.

Thus, it can be seen that the seed and seedling are at a location where the salinity hazard is not the greatest. To avoid high-salt spots, bed shapes have been designed to plant on the side of the ridge or even in a hollow or dip in the bed to locate the plant where salt accumulation is the lower.



Distribution of Salt in a Cotton Planting

This basic principle of salt movement and final distribution across ridges is the same regardless of the type of row crop grown.

Barren spots often called "hard spots" or "dry spots" in fields may result from a lack of careful attention to leveling which leaves high spots, some of which are imperceptible. This condition is accentuated in fields that do not get sufficient water for good crop growth and leaching.

Small changes in soil texture or soil compaction also are conducive to hard spots or dry-spot formations. The dry-spot problem is more prominent in perennial crops such as alfalfa than annual crops where the soil is tilled each year.

Organic Matter And Crop Residues

Whenever it is possible, organic residues should be worked into the soil. Organic matter aids formation of desirable soil structure which in turn controls water penetration and movement in soils.

Although organic matter is important as an aid to favorable water penetration and retention, unless the soils are very low and the cost of the organic material is favorably low, rarely does it pay to buy organic matter to apply to the soil of irrigated agriculture. Manures from pen-fed cattle usually are very high in salts. Municipal composts, on the other hand, have been found to be favorably low in salts.

Fairly large quantities, 10-20 tons/A, must be added. Farmers must depend largely upon the return of crop residue to maintain and improve the organic matter of the soil.

Crop-Land Selection

Selection of land for growing crops is perhaps one of the most important soil-management practices to insure permanent irrigated agriculture. Where water quality is poor and not plentiful, only the best land should be selected for crop production.

Poor land not only requires more water per crop unit produced, but requires a higher investment per unit of product. Arrangement of irrigation systems and farm management units to utilize the best land for intensive farming first, should be made. The farming operations should be made flexible to take full advantage of seasons and years having different availabilities of water.

Soils that require the least quantity of water **per unit of crop produced** should be used during periods of droughts; whereas, other soils should be leveled and prepared to take advantage of those periods when water is more plentiful.

All soils cannot be managed alike. For example, sandy soils that are readily permeable require much less attention to leaching than soils of fine texture such as silts and clays.

More water must be used on silts and clays to maintain favorable salt balances than sandy and porous soils. Some soils require only one leaching a year or even once every two or three years; whereas, others will require two or more leachings.

Cultural Management Practices To Make Most Effective Use of Water

Saline agriculture not only depends upon good soil and water management practices but also on crop management. Selection of the proper crops tolerant to salts, seed placement to avoid loss of plants during the critical germination and seedling stage of growth, rotation of crops, stand establishment, and a thorough understanding of the osmotic tension factor in limiting growth on saline substrates such as arid land soils, are important crop-management factors that must be known if a permanent agriculture is to exist in irrigated areas.

Relative Salt Tolerance Of Crop Plants

Crops vary widely in tolerance to salts. Moreover, varieties of the same crop vary considerably. For example, significant varietal differences have been claimed for **cotton, barley,** and **grain sorghum.** Climatic differences may influence greatly the reactions to salinity.

The USDA Salinity Laboratory at Riverside, California, has provided basic information concerning the "Relative Tolerance of Certain Crop Plants to Salt." (See appendix.)

The values given are **relative** and the choice of suitable salt-tolerant varieties should be evaluated with reference to the conditions under which the crop is grown. Evidence is available showing that successful cotton lint yields have been obtained at $EC_e \times 10^3$ values up to 20 or 23 mmhos in certain Pecos River Basin areas in Texas.

Whether or not these yields of about 2 bales per acre represent "50-percent decrement" in yield as compared to yields on non-saline soils in this climatic condition is not known since all the soils in this area growing cotton are saline. (A saline soil is defined as having a conductivity of the saturation extract of more than 4 mmhs/cm at 25°C and an exchangeable-sodium-percentage of less than 15.) Two bales of cotton per acre, however, have been economically satisfactory for most growers in this area.

On the basis of field experience in very saline areas such as the Red Bluff Water Control District along the Pecos River in Texas, the leaching percentage for cotton can be lessened considerably from what the USDA Salinity Laboratory Handbook figure suggests.

Seed Placement

Design of cultural practices to place the seed in the bed where it is lowest in salts offers attractive possibilities for reducing loss of stand by high osmotic moisture-stress damage to germination. Modification of the planting practice to minimize the tendency for salts to accumulate around the seed and to improve stand of crops that are salt sensitive during germination, have been suggested.

Crop Selection

Crop selection to provide varieties that are tolerant to saline conditions continues to offer one of the best means of combatting excessive salinity. Crop selection and good cultural management practices can mean the difference between success and failure.

Crop Rotation

Crop rotation often has proved valuable to reduce danger of soil structure deterioration due to overuse of row-crop culture. Most effective use can be made of land by adopting a crop rotation and land rotation compatible with the availability of waters of different quality from year to year as well as to the quantity available.

Concluding Statement

Practices in farming in the Pecos Valley and basin area as well as in parts of Arizona, New Mexico, Nevada, and California have clearly indicated that waters two to three times as saline as those indicated as permissible for crop use by the water classification schemes, have been used with economic crop returns. In each instance, however, special conditions and/or management practices have been involved.

It is fair to predict that more saline waters than those presently recommended by the literature on water classification will be used effectively to grow crops in a permanent agricultural system.

Soil and water management practices must be given careful attention when saline waters are used. Cultural practices to avoid accumulation of unfavorable concentrations of salts on or near the surface, particularly when the plants are small, must be employed.

Soil management practices in areas where salty waters are used for growing crops should include the restriction of salty waters to only the most permeable soils. Salty water can be used most effectively in leaching of salts and reclamation. Unsuitable land of low permeability must be set aside until such time as better quality of water is available in abundance for growing crops.

Crop-management practices should be employed to overcome the adverse effects of soluble salts in soils, and maintain an efficient permanent agriculture in arid and semiarid regions where salts tend to accumulate under conditions of irrigated agriculture. These practices include: selection of crops and varieties most tolerant to salt, effective placement of seed, rotation of crops, and development and adoption of effective cultural practices to improve stand establishment.

Appendix I

Symbols and Definitions

Absorption — The process by which a substance is taken into and included within another substance. For example, intake of water by soil, or intake of gases, water, nutrients, or other substances by plants.

Aggregate — A group of soil particles cohering so as to behave as a unit. Soil crumb or soil aggregate.

Alkali Soil — Also more recently called **"sodic"** soil. A soil that contains sufficient exchangeable sodium to interfere with the growth of most crop plants, either with or without appreciable quantities of soluble salts.

Alkaline soil — A soil that has an alkaline reaction. The saturated-soil-paste extract exceeds pH 7.0.

Electrical conductivity — (EC). Electrical conductivity of a saturated-soil-paste extract, for example, is reported in mhos/cm. It is a reciprocal of the electrical resistivity. Resistivity is expressed in ohms.

Exchangeable cations — A cation (positively charged element; such as, calcium, magnesium, sodium, potassium, hydrogen) that is adsorbed **on** the exchange complex of soils and which is capable of exchanging with other cations. C.E.C.

Infiltration — The downward entry of water into soil.

Leaching — The process of removal of soluble substances by the passage of water through the soil.

Leaching Requirement — (LR) The fraction of the water entering the soil that must pass through the root zone to prevent soil salinity from exceeding a specified level.

Leaching Percentage — (LP) The percentage of water that must be leached through the effective root zone to control soluble salt accumulation in soil at a selected level.

Non-saline-sodic soil — A soil that contains sufficient exchangeable sodium to interfere with the growth of most crops and does not contain appreciable quantities of soluble salt. The exchangeable-sodium-percentage is greater than 15 and the EC_e is less than 4 millimhos per centimeter. The pH usually is greater than 8.5.

Osmotic pressure — (OP) The equivalent negative pressure that influences the rate of diffusion of water through a semipermeable membrane.

Percolation — A term applied to the downward flow of water through soil, at or near a saturated condition at hydraulic gradients of 1 or less.

Permeability — The state or condition of a porous medium, such as the soil, which is related to the ease or ability to take and transmit water.

Reclamation — The process of reclaiming a soil for agricultural purposes by removing excess salts or excess exchangeable sodium in soil.

Saline — Alkali soil — (Same as saline-sodic soil) A soil containing sufficient exchangeable sodium to interfere with the growth of most adapted crop plants and containing appreciable quantities of soluble salt.

Saline soil — A nonsodic soil containing soluble salts in such quantities that they interfere with growth of most plants.

Saturated-soil-paste — A mixture of soil and water such that all the pore spaces are just saturated with water. The extract of this paste is called a saturated-soil-paste extract. Extraction is done by vacuum, pressure or centrifugation. The EC_e is the electrical conductivity of this saturated-soil-paste extract.

Appendix II

Conversion Factors

1. Tons per acre-foot (t.a.f.)
   t.a.f. = ppm x 0.00136
   t.a.f. = (EC x 10^3) (0.88)
   t.a.f. x 735 = ppm
2. Conductivity to —
   ppm = (640) (EC x 10^3)
   t.a.f. x 1.136 = EC x 10^3
3. Osmotic Pressure
   O.P. = (EC x 10^3) (0.36)
4. 1 cubic-foot/sec./24 hr. = 1.98 A.F.
5. Wetting of soil to field capacity

$$d = \frac{PAsD}{100}$$

d = inches applied
P = F.C.-P.W.
(available moist.
% H_2O — dry wt.)
As = Bulk density
D = depth of soil in inches

Example: Sandy loam = 1″/1 ft.
Loam = 1.75″/1 ft.
Clay loam = 2.25/1 ft.
Clay = 2.00/1 ft.

Relative Tolerance of Field Crops to Salt[1]

$EC_e \times 10^3 = 16$*	$EC_e \times 10^3 = 10$	$EC_e \times 10^3 = 4$
Barley (grain)	Rye (grain)	Field beans
Sugar beet	Wheat (grain)	
Rape	Oats (grain)	
Cotton	Rice	
	Sorghum (grain)	
	Corn (field)	
	Flax	
	Sunflower	
	Castorbeans	
$EC_e \times 10^3 = 10$	$EC_e \times 10^3 = 6$	

[1] Reference: USDA Agricultural Handbook No. 60, 1954. Editor L. A. Richards, U. S. Salinity Laboratory, Riverside, California.

* The numbers following $EC_e \times 10^3$ are the electrical conductivity values of the saturation extract in millimhos per centimeter at 25°C. associated with 50-percent decrease in yield

Selected References

1. **Bernstein, Leon.** Salt Tolerance of Plants and the Potential Use of Saline Waters for Irrigation. Nat'l Acad. Sci. — Nat'l Res. Council. Pub. 942, 1964.

2. **Bernstein, Leon.** Tolerance of Plants to Salinity. Jour. Irrig. and Drainage Div. Proc. Am. Soc. Civil Eng., 1961.

3. **Bernstein, Leon.** Salt Tolerance of Plants. USDA Infor. Bul. No. 283, 1964.

4. **Bower, C. A.** Prediction of the Effects of Irrigation Waters on Soils. Proc. UNESCO Arid Zone Symposium, Tehran, Iran. 215-22, 1959.

5. **Buehrer, T. F.; and Williams, J. A.** The Hydrolysis of Calcium Carbonate and Its Relation to the Alkalinity of Calcareous Soils. Univ. Ariz. Agr. Expt. Sta. Tech. Bul. **64,** 1936.

6. **Fuller, W. H.; and Ray, H. E.** Gypsum and Sulfur Bearing Amendments for Arizona Soils. Univ. Ariz. Agr. Expt. Sta. and Exten. Serv. Bul. No. A-27, 1962.

7. **Fuller, W. H.** Reactions of Nitrogenous Fertilizers in Calcareous Soils. Agr. Food. Chem. 11: 188-93, 1963.

8. **Fuller, W. H.** Reclamation of Saline and Alkali Soils. Plant Food Review. p. 7-9, 1962.

9. **Gardner, W. R.; and Nieman, R. H.** Lower Limit of Water Availability to Plants. Science, 143:1460-62, 1964.

10. **Harris, Karl; Erie, Leonard J.; and Fuller, W. H.** Minimum Tillage in the Southwest. Univ. Ariz. Agric. Expt. Sta. and Ext. Serv. Bul. A-39, 1965.

11. **Hayward, H. E.** The Salinity Factor in the Re-use of Waste Waters. **The Future of Arid Lands.** AAAS, 1965.

12. **Hayward, H. E.; and Bernstein, L.** Plant-Growth Relationships on Salt-Affected Soils. Bot. Rev. **24:** 584-635, 1958.

13. **Reeve, R. C.** The Relation of Salinity to Irrigation and Drainage Requirements. Internatl. Comm. on Irrig. and Drainage, Third Congr. Question 10R. 10, pp. 10. 175-10.187, 1957.

14. **Reeve, R. C.; and Bower, C. A.** Use of High-Salt Waters as a Flocculent and Source of Divalent Cations for Reclaiming Sodic Soils. Soil Sc., 90. 139-144, 1960.

15. **Richards, L. A.** Availability of Water to Crops on Saline Soil. USDA Agri. Inform. Bul. No. 210, 1959.

16. **Smith, H. V.; Draper, G. E.; and Fuller, W. H.** The Quality of Arizona Irrigation Waters. Univ. Ariz. Agr. Expt. Sta. Report 223, 1964.

17. **Smith, H. V.; Draper, G. E.; Buehrer, T. F.; Fuller, W. H.; and Marx, G. W.** The Quality of Arizona's Domestic Waters. Univ. Ariz. Agr. Expt. Sta. Report 217, 1963.

18. **Thorne, D. W.; and Peterson, H. B.** Irrigated Soils, Their Fertility and Management. The Blakiston Co. Inc., New York.

19. **USDA.** Diagnosis and Improvement of Saline and Alkali Soils. USDA Agr. Handbook No. 60, 1954.

20. **Wilcox, L. V.; and Resch, W. F.** Salt Balance and Leaching Requirement in Irrigated Lands. USDA Tech Bul. 1290, 1963.

This publication is issued by the
Cooperative Extension Service and
the Agricultural Experiment Station
of The University of Arizona. See
your local County Extension Agent
for additional information.