IV. Dealing with salinity

Breeding more salt-tolerant crops, transferring salinity tolerance from other organisms to crop plants, building regional drainage systems, and devising improved irrigation and management techniques are the principal options.

Management alternatives: crop, water, and soil

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All waters and soils contain salt. Even nonsaline irrigation waters like those of the Sacramento-San Joaquin Delta contain enough salt to create a hazard if drainage is insufficient. Delta channel waters typically have an electrical conductivity of about 0.2 dS/m (about 128 mg/L salt) and contain 350 pounds of salt per acre-foot of water. With adequate subsurface drainage and an average annual rainfall of 15 inches, however, neither salinity nor a shallow water table is a problem.

In contrast, Colorado River water contains six times more salt. Soils in the Imperial Valley, for example, that receive less than 3 inches of rainfall annually can become saline quickly without adequate leaching.

The threat of salinity is thus always present in irrigated agriculture. But with proper management, appropriate crop selection, and adequate drainage, full crop productivity is possible throughout California using most present water supplies.

Salts are leached below the root zone whenever the amount of water infiltrated exceeds that evapotranspired. In many regions of California, winter rainfall is normally adequate to leach accumulated salts. Where rainfall is insufficient or irrigation waters are saline, provisions must be made for adequate leaching: the key to salinity control is a net downward movement of soil water through the root zone. The choice of salinity control measures depends on the quality and quantity of the applied water, the irrigation system and its management, drainage conditions, and agronomic techniques.

Leaching requirement

The leaching fraction — the fraction of the applied water (irrigation plus rainfall) that passes through the root zone — carries dissolved salts below the root zone. The smallest leaching fraction that maintains full crop productivity is known as the leaching requirement. It depends on the salt content of the irrigation water and the salt tolerance of the crop.

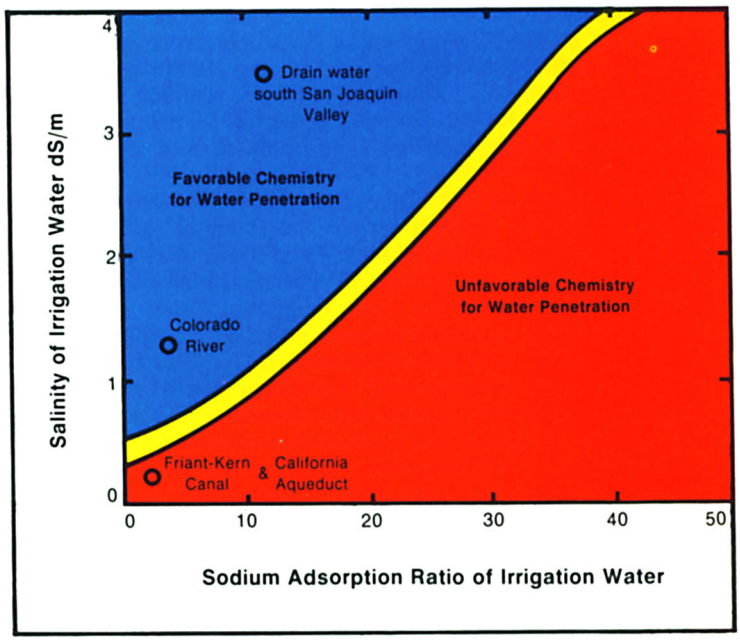
Almost no leaching is required with most of the surface irrigation waters in central and northern California (see table). Application uniformity of irrigation water seldom exceeds 85 percent. If 15 percent extra water is applied to compensate for nonuniformity, some of the leaching requirement is also met. In many areas, rainfall adds a safety factor. With waters like the Colorado River, however, leaching is mandatory for moderately sensitive and sensitive crops. Many salt-sensitive fruit and vegetable crops cannot be grown without risking yield reduction when irrigation waters have a salinity much greater than 1.5 dS/m (about 960 mg/L).

Two conditions in addition to the leaching requirement are essential in avoiding salinity hazards: (1) infiltration rates into the soil must be high enough to maintain adequate soil water content and associated soil matrix potential (a measure of the amount of work required to extract water attached to the soil matrix or soil surfaces) to prevent water stress in the plant; and (2) subsurface drainage must be adequate to leach salts and prevent a shallow water table.

Water penetration

Individual salt constituents as well as total salinity of the irrigation water affect the stability of soil structure and, hence, water penetration. Regardless of the sodium content, waters

Fig. 1. Both salinity and sodium adsorption ratios of applied water affect its penetration into soil.



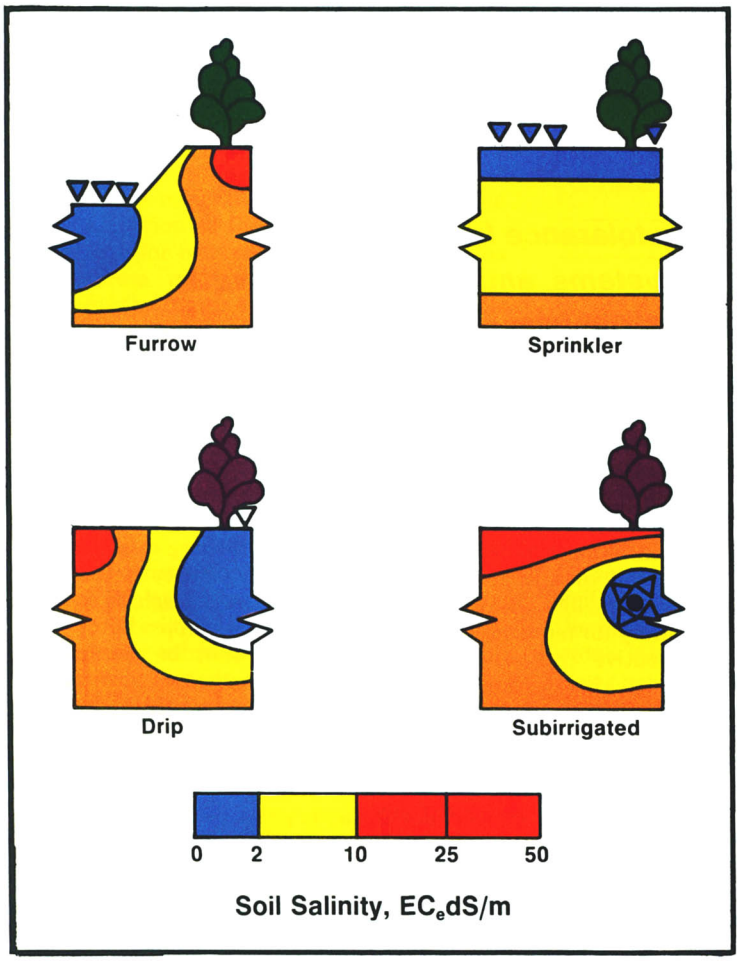


Fig. 2. The method of water application affects salt distribution in the soil. With sprinklers, salt is uniform laterally and increases with depth. In furrow or drip, salinity is low beneath the water source, increases with depth, and is high near the surface between sources. With subsurface systems, salinity is high above the water source.

with salinities of less than 0.3 dS/m (about 200 mg/L), cause clays to swell; the swelling results in the breakdown of soil aggregates, promotes soil crusting, and reduces water penetration. High salinity levels reduce swelling and aggregate breakdown (dispersion), whereas high proportions of sodium have the opposite effect.

Both salinity and the sodium adsorption ratio of the applied water must be considered in assessing the potential effects of water quality on soil physical properties (fig. 1). Physical properties such as soil crusting also depend on other factors, including water drop impact, ground cover, clay mineralogy, and soil texture. These properties may have a greater influence on water penetration than do the chemical factors.

If the salinity and sodium adsorption ratio of the irrigation water are close to the boundary (broad line in fig. 1) and poor water penetration is a problem, there are several management options. Tillage would destroy the crust and increase water penetration for at least one irrigation. Other alternatives include changing the water composition with chemical amendments or blending dilute surface water with more saline well waters. Sulfuric acid or sulfur dioxide could be added to the water to lower the bicarbonate concentration, thereby reducing the potential sodium adsorption ratio of the infiltrating water and the exchangeable sodium of the surface soil. Gypsum could be applied to the soil surface or added to the water to increase the salinity and reduce the sodium adsorption ratio of the infiltrating water. Sulfuric acid could be applied to calcareous soil to reduce the exchangeable sodium of the surface and to increase soil salinity temporarily. Another example of the use of acid, practiced in the Salinas Valley, is the band application of phosphoric acid over the seed row of lettuce, which temporarily reduces soil crust development and helps plant emergence.

Salt distribution in root zone

When water is taken up by plants or evaporates from the soil surface, most of the salts are left behind in the soil. If more water is added than the plant uses, the excess water leaches some salt down out of the root zone. After an irrigation, salts added previously are carried deeper into the soil profile. If the amount of water applied is not more than the amount used, salt accumulates within the wetted soil depth during the irrigation.

Salt distribution within the root zone is influenced by the water extraction pattern of the crop. In work conducted at the U.S. Salinity Laboratory, alfalfa and tall fescue grown on Pachappa sandy loam were treated the same: the electrical conductivity of the irrigation water was 4 dS/m (about 2,500 mg/L salt) and the leaching fraction was 0.2. Tall fescue extracted most of its water above a soil depth of 2 feet, and most of the salinity increase occurred above that depth. Comparable water extraction by alfalfa occurred to a depth of 4 feet, where the soil salinity was about the same in both crops.

The method of water application also affects salt distribution in the soil (fig. 2). Under sprinkler irrigation, lateral salt distribution is relatively uniform, but soil salinity increases with depth. Under furrow or drip, salinity levels are low immediately beneath the water source and increase with depth. Midway between the furrow or drip sources, soil salinity is high; levels may be highest at the soil surface, particularly if the wetting patterns do not overlap and the soil remains dry. The distribution resulting from point sources, such as drip systems with widely spaced emitters, increases in all directions from the emitter; as the rate of water application increases, the salinity distribution changes from elliptical (with the major axis in the vertical direction) to circular.

Subsurface systems provide no means of leaching the soil above the source of water. Continuous upward water movement to the evaporating surface causes salt to accumulate near the soil surface. Unless the soil is leached by rainfall or surface irrigation, salt accumulation to toxic levels is a certainty.

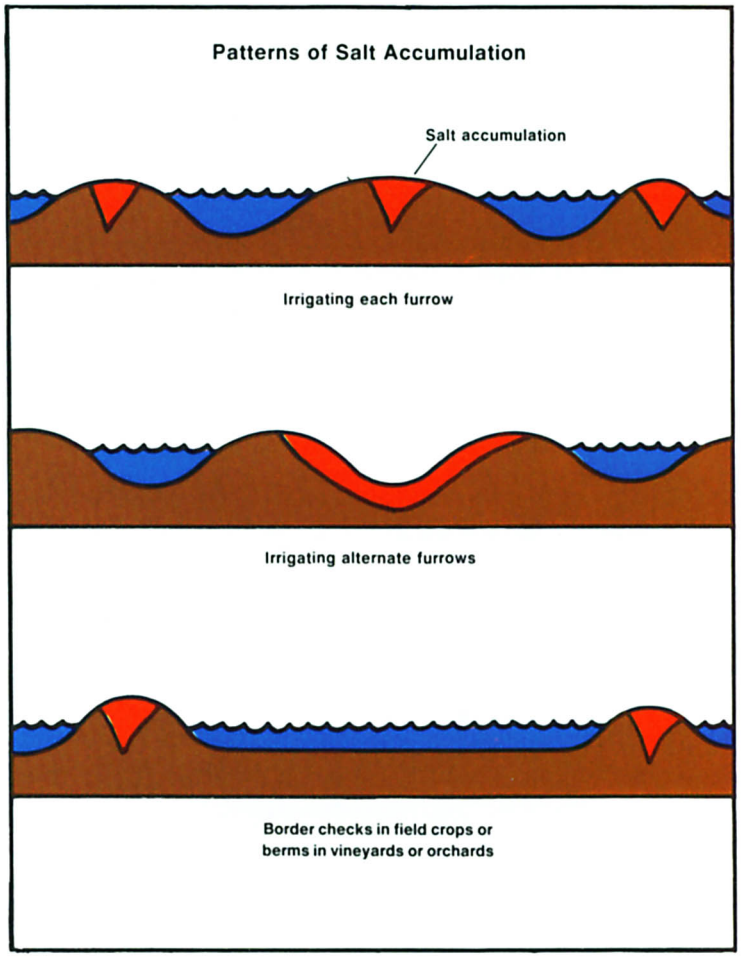
Agronomic management

Crop selection. By selecting an appropriate crop rotation, a grower often can maintain productivity. The soil salt content may increase during one crop and decrease during a following crop. For example, alfalfa irrigation in the Imperial Valley is often just sufficient to meet the crop's evapotranspiration needs, because no more water will infiltrate. The result is inadequate leaching and increased soil salinity. If alfalfa is rotated with winter crops that have a low evapotranspiration requirement, additional irrigation water can be applied for leaching.

There is about a tenfold range in salt tolerance among agricultural crops. In areas where only saline irrigation water is available, where shallow, saline water tables prevail, or where soil permeability is low, achieving nonsaline conditions may not be economically feasible. An alternative is to select crops that produce satisfactory yields under saline conditions.

Seed placement. Obtaining an adequate plant stand in saline furrow-irrigated fields is often difficult. One way of

Fig. 3. Irrigation management affects salt accumulation and is one way to ensure low salinity around germinating seeds.



compensating for poor germination is to plant more seed than is required. Another approach is to ensure low salinity around the germinating seeds by using special planting practices, bed shapes, or irrigation management.

In furrow-irrigated soils, dissolved salts move from the wet furrow and accumulate in raised beds (fig. 3). A double-row, raised planting bed places the seeds near the shoulder of the bed and away from the area of greatest salt accumulation. Planting the seed at the ridge center is inadvisable, unless alternate furrow irrigation techniques are used. With these techniques, salts can be moved beyond the single-seed row to the nonirrigated side of the planting bed. Double-row planting under alternate-furrow irrigation is not recommended, because salt accumulates on the edge of the bed away from the irrigation furrow. Other alternatives include off-center, single-row planting on the shoulder of the bed close to the water furrow, or on sloping beds just above the water line.

With either single- or double-row plantings in salt-affected soils, increasing the depth of water in the furrow may also improve germination. Irrigation should be continued until the wetting front has moved well past the seed row. During the first cultivation after planting, the sloped bed can be converted to a conventional raised bed.

Sprinkler irrigation is often used to germinate salt-sensitive vegetable crops such as lettuce. It is very effective in leaching the surface soil and provides a nonsaline environment for germination and initial stages of plant growth. The uniformity of leaching is high and the amount of water required is small. The primary advantage, however, is the uniformity of germination: less seed is required and the cost of thinning is reduced.

Soil profile modification. Some soils have layers that impede or inhibit root and water penetration. Mixing these layers by deep plowing or penetrating them with chisels or slip plows may simplify water management and salinity control. The improvement of water penetration and internal drainage is generally short-lived, however, and must be repeated. Deep tillage often brings saline subsoils up into the root zone, so that a salt-tolerant annual crop like barley must be grown the first year, and more than the normal amount of water applied for extra leaching.

Accurate grading increases uniformity of water distribution on surface-irrigated fields. High spots in fields reduce water intake and may lead to salinity problems; they are removed best with laser-controlled leveling equipment. As an alternative, sprinkler or drip irrigation can be used without precise grading.

Incorporation of organic residues into the surface soil improves water penetration. Crop residues, and particularly winter cover crops or green mulches, are beneficial. In a recent study conducted by U.S. Department of Agriculture Agricultural Research Service (ARS) scientists at Brawley, animal manure applied at a rate of 20 tons per acre to a Holtville silty clay soil doubled water infiltration rates. Since animal manure contains about 10 percent salt, a leaching preirrigation is usually applied after manure application and incorporation.

Rainfall

Mulching or leaving the soil fallow to conserve rainfall can be an effective method of reducing soil salinity. Mulching decreases soil crusting and reduces evaporation, thereby decreasing runoff and increasing infiltration. Almost any organic material or rough cultivated soil can be an effective mulch.

In a sandy soil, 8 inches of rainfall that penetrates the soil removes about 50 percent of the salts in the surface 3 feet; in a clay soil, the corresponding depth is 1½ feet. If the soil is wet before rains occur, the depth of leaching is somewhat greater.

Where salinity is a problem in perennial crops, such as citrus and avocados, reducing irrigation before the rainy season is a dubious technique to maximize the use of rainfall. Trees may be exposed to both water and salt stress before rain occurs. Rainfall may cause downward and lateral movement of salts that have accumulated between emitters or sprinklers near the soil surface, resulting in salinization of active portions of the root zone. In San Diego County avocado orchards irrigated with Colorado River water by drip methods or low-angle sprinklers, the recommended practice is to continue irrigation until at least 2 inches of rainfall has occurred in a period of no more than 14 days.

Reclamation

Saline soils. Reclamation generally refers to reducing soil salinity to acceptable levels by leaching or reducing soil sodicity by applying amendments in conjunction with leaching. Electrical conductivities of soil saturation extracts that exceed 3 dS/m (about 2,000 mg/L salt) are of concern for moderately tolerant crops; if values are greater than 10 dS/m (6,400 mg/L), reclamation would probably improve the productivity of any crop.

The salinity of the upper 2 feet of soil is of most concern. The application of 4 to 8 inches of water before planting, coupled with a 4-inch application immediately after planting,

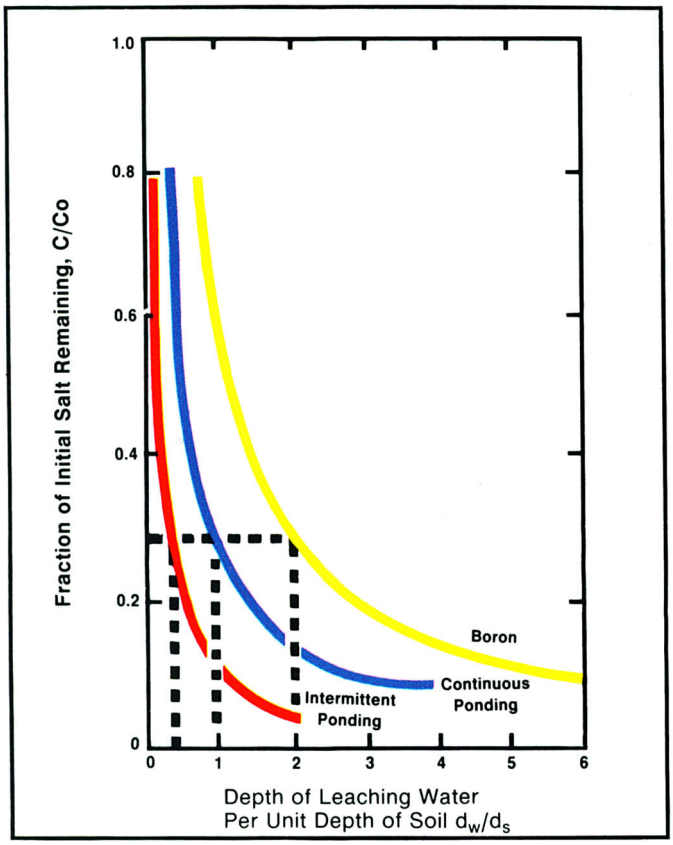


Fig. 4. Water needed to leach saline soils or those high in boron by ponding, expressed in depth of water (dw) per unit depth of soil (ds). Salt or boron removal is expressed as the fraction C/C_0 where C represents the final concentration and C_0 the corresponding initial concentration.

is often sufficient for reclamation of this zone. Salinity levels higher than 10 dS/m may require more leaching than preirrigation can provide.

The amount of water used for reclamation of very saline soils depends on the water application technique, as was first demonstrated by researchers with the Department of Land, Air, and Water Resources at UC Davis. For continuous ponding, leaching with a depth of water equivalent to the depth of soil to be reclaimed reduces the fraction of initial salt remaining to about 0.3, which corresponds to removing about 70 percent of the soluble salts initially present. This is illustrated by the broken blue lines in figure 4 at C/C_o of 0.3. To remove 70 percent of the soluble salts from a 2-foot-deep soil profile would require 2 feet of water. Less than half as much water would be required by intermittent applications of ponded water or sprinkling. The larger the percentage of water flowing through fine pores, as occurs when sprinkling, the more efficiently the leaching water displaces the saline solution.

Sprinkling is similar to intermittent ponding in leaching efficiency. In some cases, sprinkling may provide even greater efficiency, particularly where applications are at low rates or are intermittent. An added advantage of sprinkling over ponding is that precise land leveling is not required. One possible disadvantage of both methods is that they may take longer than continuous ponding: in one study conducted in California by UC researchers, leaching of a clay loam soil took twice as long with intermittent as with continuous ponding. In another study on silty clay soil, ARS researchers found that sprinkling, intermittent ponding, and continuous ponding all achieved the same degree of leaching in the same amount of time.

Leaching requirements for typical irrigation waters in California as related to salt tolerance of the crop

Salinity of applied water	Leaching requirement at following crop tolerance:			
	Sensitive	Moderately sensitive	Moderately tolerant	Tolerant
dS/m				
0.05 (Friant-Kern Canal)	0.01	0.01	0.01	0.01
0.3 (Calif. Aqueduct)	0.05	0.02	0.02	0.02
1.3 (Colorado River)	0.14	0.07	0.04	0.02
5.0 (reused drainage)	*	0.27	0.15	0.10

*Salinity of applied water is too high to achieve adequate leaching.

Boron removal. Excess boron requires more water for leaching than other salts, because it can be tightly adsorbed on soil particles. About twice as much water is required to remove a given fraction of boron as to remove the same fraction of soluble salts by continuous ponding (fig. 4). Soils inherently high in the element require periodic leaching to remove boron released slowly from the soil matrix. Boron leaching efficiency does not appear to be influenced by the method of water application.

Sodic soils. Reclamation of sodic soils requires the replacement of exchangeable sodium by calcium, followed by leaching. If a native soil does not contain sufficient soluble calcium, it can be added in the form of a soluble salt, or soil lime may be made soluble by the addition of acid or acid-forming materials. The most common additive is gypsum (calcium sulfate), which is mixed into the soil or dissolved in the irrigation water. Acid or acid-forming additives include sulfuric acid, iron sulfate, aluminum sulfate, and sulfur.

Different amendments reclaim soils at different rates: ranked from fast to slow are concentrated sulfuric acid, gypsum, and sulfur. The high salt concentration of the soil solution that results from using sulfuric acid increases the rate of water flow through the soil, but special equipment is needed to handle acid safely. Microbiological oxidization of elemental sulfur, a slow process in cool soils, is required before it is effective in dissolving soil lime.

The amount of gypsum or other amendments to be added to the soil can be estimated from the amount of exchangeable sodium to be replaced by calcium. One ton of gypsum per acre produces about a 10 percent reduction in exchangeable sodium percentage in 0.5 foot of a sandy soil; the comparable reduction in a clay soil is about 3 percent. The amount of water required to dissolve a ton of gypsum ranges from about 0.25 to 1 acre-foot. Reclamation with gypsum may require annual or semiannual applications for several years until the soil is reclaimed to a depth of 2 to 3 feet.

Conclusion

Options in managing irrigation water and soil become more limited with increasing salinity or sodicity. The general procedures followed in preventing or alleviating problems include: verification that drainage is adequate; measurement of initial salinity and sodicity of the soil, and reclamation if necessary; determination of the chemical composition of the irrigation water and assessment of potential soil and crop hazards associated with its use; and leaching, using only as much water as is needed to prevent salt accumulation.

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