table, produces conditions for accumulation of salts. Extensive borings along the west side reveal large concentrations of soluble salt and gypsum in some areas, as reported by L. D. Doneen and K. K. Tanji, of the Department of Land, Air, and Water Resources, UC Davis.

Although groundwater is widely used for crop production, surface water has been introduced from the Sacramento Valley through the Delta Mendota Canal, the California Aqueduct, and the East Side Canal. The salinity of this water is quite low — on the order of 230 mg/L — but the total salt imported is greater than 300,000 tons per year.

The system is gradually moving into a more critical stage, because conditions for additional deterioration are present. There are extensive areas where both excessively and slightly soluble salts are present and soils are slowly permeable. Importation of water brings in additional salt, releases immobilized salts in surface soils, increases the area affected by shallow water tables, and intensifies the hazards of salinity. Disposition of salts, water quality requirements, and the effect of salts on soils and plants are therefore of primary concern.

Disposition of salts

Problems and solutions of water and salt flow are site-specific. Evaluating the relative contributions of sources of salt to the root zone, to irrigation return flows, and to deep percolation and subsurface drainage is sometimes accomplished by salt and water balance methods. Salt balance methods are applied to both small-scale farm-size and large-scale river basin systems.

Irrigated areas develop problems when more salt enters the soil solution than is removed. Both concentration and type of salt are important. Soils and plants react differently to different salts.

Control of salt through removal by crops is not significant, since plants absorb only small quantities of salt. Although rainfall may be an important source of salt deposition in coastal areas, the real significance of rainfall in irrigated regions may often be associated with displacement of salt from the root zone and replenishment of the soil water. Rainfall may be as much as 30 percent more efficient for leaching salt than many irrigation methods, as shown by Miller, Biggar, and Nielsen, at UC Davis.

If irrigation is practiced in a particular area, it is implied that either rainfall is insufficient or water use does not coincide with the supply. This mismatch in use and supply may occur with respect to time as well as location. The importation of water into such a region inevitably leads to the development of shallow water tables and accumulation of excess salt. Irrigation water then becomes an important source of salt to the plant root zone, and the larger the concentration and volume of water applied, the greater the probability that problems will develop. Even after the initial reduction in native salinity found in soils of the west side of the Valley, water importation enhances the tendency toward increased area of perched water tables and accumulation of salt. In addition, problems of saline drainage water disposal and degradation of supply water become more critical.

Deposition of salt in the soil profile is partly a consequence of the differential removal of water by plant transpiration, leaving the salt in the soil. An irrigation water containing 100 mg/L total dissolved solids will deposit 0.136 ton of salt in the soil for each acre-foot per acre of water applied. Some cropping programs require 3 acre-feet of water annually; if the water contains 1,000 mg/L, a concentration common to many sources of water, 4.1 tons of salt will be applied to the soil in one season.

A shallow water table may inhibit plant growth because of excess salinity and water. Natural salinization of soils can result from shallow water tables and upward movement of water and salt due to evaporation and drying at the soil surface, conditions that exist in irrigated regions. Crops that derive part of their water requirements from shallow water tables are more salt-tolerant than others, but, depending on the saline content of the shallow water, even they will produce lower yields than under more favorable conditions.

Not all salt in the root zone comes from irrigation water or water tables. Some soils in their natural state contain varying quantities of slightly soluble solid forms of some salts, which continue to dissolve as water moves through the soil. In some places, these dissolving minerals, such as calcium sulfate, contribute more salinity to the soil solution and drainage water than is applied in the irrigation water. Areas on the west side of the San Joaquin Valley are noted for this effect.

Soil salinity control

A major process for salinity control depends on leaching water through the root zone to remove excess salt and limit the dissolved salt content to the tolerance limits of the crop to be grown. Movement of water through the profile is necessary to remove excess soluble salt from the root zone of crops but is undesirable when it dissolves precipitated salts, since excess water and salt increase drainage requirements and the salt degrades groundwaters.

It is prudent to minimize the flow of water through the soil profile to reduce dissolution of soil minerals and promote precipitation of slightly soluble carbonates and sulfate minerals in the profile. Since precipitated minerals have little effect on plant growth or soil properties, the reduction in salt load should be beneficial to groundwater and surface flows. Unfortunately, neither of the mentioned processes can prevent a soil from eventually becoming salinized. Some means of collecting saline drainage waters is essential to balance salt inflow and outflow and maintain a favorable salt environment in the root zone of a crop. In some cases, crop selection may be dictated by the achievable salt balance, but the higher the concentration of soluble salts in the root zone, the narrower the choice of crops and the smaller the economic returns.

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Effect of salt on soils

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When water is applied, particles of soils with high smectite (montmorillonite) clay content may swell considerably due to hydration of expandable soil minerals. Such swelling reduces the cross-sectional area of soil pores. The process of swelling is more pronounced in the presence of high sodium or low salt concentrations, or both, in the soil water.

Dispersion of fine soil particles is controlled by a similar mechanism. Dispersion is directly influenced by ions adsorbed on particle surfaces, particularly clay minerals. The presence of high sodium, especially at low salt concentration in the soil water, causes dispersion and movement of fine particles within the pores. The particles may then become lodged in smaller pores, blocking water or air.

Swelling and dispersion are both in-

Salinity swells soil clays, leading to crust formation and reduced water transmission through the soil.

fluenced by clay mineralogy, the amount of sodium adsorbed on the soil, and the salt concentration in the soil water. In general, dispersion is greater in smectite clays than in kaolinite clays, and in kaolinite clays than in micas. Considerable dispersion and swelling may occur with only small amounts of sodium adsorbed on the soil if the concentration of salt in the soil water is very low, approaching that of rainwater. Less swelling and dispersion will occur with increasing concentrations of salt in the soil water.

Dispersion and swelling are major mechanisms by which surface soil aggregates break down. The resulting surface seals and crusts act as layers impeding infiltration of water into the soil, diffusion of gases across the soil surface, and emergence of plant seedlings. The impact of rain or sprinkler irrigation drops and irrigation water flowing over the surface soil dislodges soil particles from aggregates through physical forces, air entrapment, dispersion, and swelling. Once the particles are dispersed, some may be moved into pores. The force of the water drops may also compact a thin layer of soil Other dispersed particles remain at the surface and settle as the surface water infiltrates, with some orientation of the clays to form a dense layer of soil a few millimeters thick. Although surface crusts occur in areas where salinity is not considered a problem, the amount of sodium and concentration of salt in rain or irrigation water will indirectly influence the degree of particle dispersion and the development of surface sealing or crusts.

Surface seals or crusts limit the movement of gases in and out of the soil profile, especially under wet conditions following irrigation or rainfall. Unless the crust cracks as the soil dries, the low rate of oxygen movement across the soil surface may result in temporarily poor aeration within the root zone and adversely affect the crop.

Swelling and dispersion of soil clays affect water transmission properties by altering the geometry or continuity of soil pores. The hydraulic properties of soil, such as hydraulic conductivity, are thus highly dependent on both the exchangeable sodium percentage and the salt concentration of the percolating soil solution. The rate of water flow through soils with a high exchangeable sodium percentage may be maintained, if the concentration of salt in the percolating solution is above a threshold value where swelling and particle dispersion are limited. However, in soils with low exchangeable sodium percentages, clay dispersion and the resulting decrease in hydraulic conductivity will occur at very low salt concentrations in the percolating solution, just as they do at high exchangeable sodium percentages and low salt in the water.

Soils of the east side of the San Joaquin Valley contain clay minerals that are easily dispersed, resulting in water absorption problems that are not readily avoided. The predominant montmorillonite soils on the west side respond to proper management of sodium and salinity.

California and Israeli researchers have recently determined that when the percolating solution is very low in salt, such as in rainwater, the susceptibility to decreased water flow due to presence of absorbed sodium depends on the potential of the soil to release salt. The released salt or electrolyte is derived from weathering of primary minerals and dissolution of calcium carbonate. If electrolyte is released at a rate sufficient to maintain the concentration of salt in the percolating solution above the level where particle dispersion occurs, the rate of water flow through the soil can be maintained at acceptable levels. Highly weathered or old soils tend to release electrolyte at a lower rate than young or calcareous soils and those with primary minerals such as feldspars and plagioclases.

The water infiltration characteristics of a soil strongly influence the type and management of the irrigation system. Soils with a moderate exchangeable sodium percentage may have reasonable water transmission rates below the soil surface due to release of electrolyte from soil minerals. Yet these same soils may have very low infiltration rates at the soil surface because of high particle dispersion and sealing caused by rainfall or irrigation water of very low salt concentrations. The presence of sodium bicarbonate in well waters along the east side of the Central Valley increases the tendency for crust formation as well as reduced permeability with depth.

Salinity might be expected to have a detrimental effect on the activity and efficiency of microorganisms responsible for nutrient cycling within soils. However, most evidence from UC research indicates that soil microorganisms are affected only at very high concentrations of salt in the soil.

K. K. Tanji (Department of Land, Air and Water Resources, UC Davis) has made detailed analyses of the salt disposition in the Panoche Drainage District. Situated in one of the salt-affected regions of the Valley, this district encompasses three irrigation districts that use a number of sources, including imported

Delta Mendota and California Aqueduct water. The supply water averaged 234 mg/L in salinity, and the soil water, assuming a doubling or tripling in concentration due to evapotranspiration, would be expected to reach nearly 700 mg/L. However, measurements and model calculations demonstrated the soil water to be 7,000 to 8,000 mg/L. This is water that would penetrate deeper into the profile and that would be captured by drains to be discharged elsewhere or recycled for crop production. The 10-fold increase in concentration is attributed to dissolution of soil minerals, principally gypsum. Although a few crops could tolerate such concentrations for selected periods, the long-term maintenance of irrigated agriculture using such waters is doubtful.

In summary, the major effects of salinity on soil properties are swelling of soil clays, dispersion of fine soil particles, crust formation, and decreases in water-transmission properties. The amount of sodium adsorbed on the soil and the amount of sodium and salt in the irrigation water greatly influence the degree to which salinity affects soil properties.

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Case history: Salton Basin

Jewell L. Meyer **Jan van Schilfgaarde**

The Salton Basin extends 200 miles from San Gorgonio Pass in the north through the Coachella, Imperial, and Mexicali valleys to the Gulf of California. The basin covers a drainage area of about 8,000 square miles and at its deepest point is 273 feet below sea level — about the same as Death Valley.

The desert climate is characterized by long hot summers, short mild winters, and sporadic rainfall averaging only about 3 inches per year. If water can be supplied, the climate and alluvial soil are ideal for many vegetable, fruit, and field crops.

Irrigation water delivery to the Imperial Valley began in June 1901. Within three years, over 150,000 acres were being planted to barley, grain sorghum, alfalfa, and cantaloupes, despite problems with transportation and water delivery, and severe living conditions for the new settlers.

In March 1905, silt that had built up in the Colorado River near the headgates south of Yuma, Arizona, diverted the first of several floods into the canal system. Flood water flowed through the canals and the Alamo River into the Salton Sea, cutting a new, 60-foot gorge, the New River. The Salton Sea, nearly dry in 1904, filled to a level of −195 feet; the sea covered 500 square miles and was 80 feet deep by early 1907, when the Southern Pacific Railway Company finally closed the breach.

The Imperial Irrigation District, formed in 1911, had consolidated most of the mutual water districts under a single entity by 1916 and enlarged its potential boundaries to over ½ million acres. With federal assistance, Imperial Dam was built on the Colorado River and the All-American Canal was constructed. Water delivery to the Imperial Valley through these facilities started in 1943.

In contrast to the Imperial Valley,

The 8,000-square-mile Salton Basin, one of the most productive agricultural areas in the world, as seen by a Landsat camera. The Salton Sea serves as the drainage basin for saline irrigation waters from the Imperial, Coachella, and Mexicali valleys.