SURVIVING SALT

Research is pointing out technologies with the potential to help farmers cope with the salt of the earth

Second of two articles

By JANET RALOFF

"Today, every arid land region of the world is in some intermediate or final stage of [salinization], and nowhere, it would seem, has there been established a genuine détente with these deceptively simple destroyers of man's vaunted accomplishments." Warren Hall made that statement before a conference of salinity experts convened at the University of Colorado in 1973. As acting director for the Interior Department's Office of Water Resources Research, his perspective reflected the frustration scientists and policymakers were facing in trying to control this simple force of nature (SN: 11/10/84, p. 298).

Eleven years later, the picture is still grim, though improving. While the number of acres affected by salinity continues to climb, there are pockets of success in reclaiming previously despoiled land and in slowing salinity's advance. What's more, research is suggesting ways to cope with the throes of salt.

At the U.S. Salinity Laboratory in Riverside, Calif., which heads research on the problem for the U.S. Department of Agriculture (USDA), studies on the biology of salt stress in plants and on the physical processes affecting salt transport in soil have been ongoing for more than 35 years. In a recent interview during his last days as director of that lab, Jan van Schilfgaarde noted that this research "has given us a better picture of the mechanisms taking place with salinity stress." But, partially because of cost, he says, "we haven't gotten very far in making use of [those] data."

Also impeding the use of much of the lab's hard-won knowledge are uncertainties over how to apply data from the highly instrumented, rigidly controlled environment of the laboratory out in the largely noninstrumented, uncontrolled environment of an irrigator's field. "*Qualitatively* we know what's happening now," van Schilfgaarde says. However, unless the water balance in a field is understood *quantitatively* — how much water goes in as irrigation or rain, how much evaporates or is taken up by plants, how much stays in the soil and how much exits in drainage — it's difficult to tailor salinity control strategies for the individual's needs, he says.

In fact, van Schilfgaarde says that until recently there has not even been an easy or affordable way to measure a field's salinity status. However, as a result of new technology developed at the lab by soil scientist James Rhoades, routine salinity diagnoses may be just over the horizon.

MEASURING SALINITY: There is water in irrigated soils, and the electrical conductivity of that water is a function of any salts present, explains Rhoades, who became acting director of the lab when van Schilfgaarde moved on to a new post. Drawing from a geophysical technique used by prospectors to locate mineral ores by assaying conductivity, Rhoades developed a four-electrode salinity probe to be inserted into soil. Resistance to current flow within the soil is measured between one pair of electrodes as an electrical current is passed through the soil between a second pair. A volume roughly 9 inches in diameter and 6 inches deep can be sampled with each poke of the probe, which was introduced commercially about four years ago.

A newer salinity monitor also owes its conceptual origins to mineral prospecting. Placing a primary electromagnetic field within soil will induce a secondary current flow in the soil that is directly proportional to the soil's conductivity. A sensor that measures this, shaped like a meter-long carpenter's level, does not even have to make contact with soil. In practice, however, readings are usually taken by laying this electromagnetic-induction sensor on the ground, first vertically, then horizontally. From its readings, calculations of salinity at specific depths are derived.

Because the scale of this device is so much larger than the other, it would be

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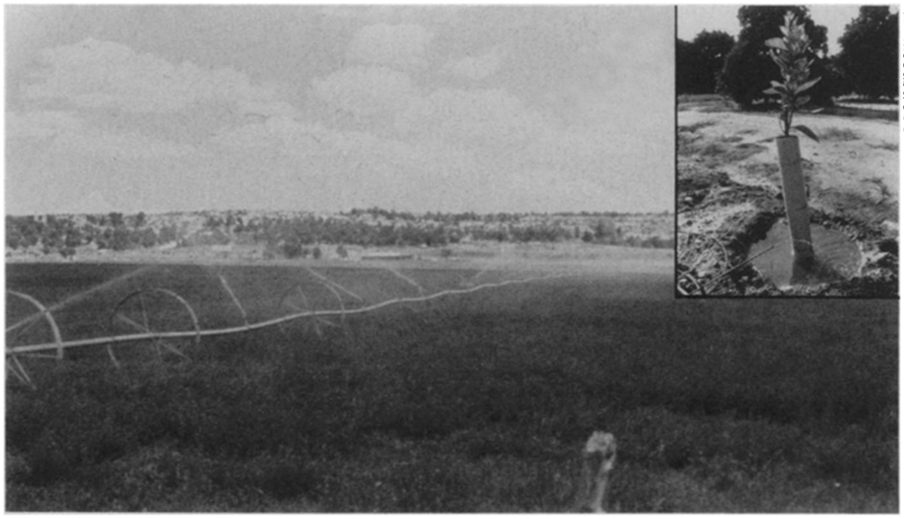
Lining irrigation ditches in cement (left ditch) improves irrigation efficiency by curbing seepage through dirt bottom.



Wheel-carried sprinklers and drip irrigators (inset) improve irrigation efficiency.

Tim McCabe/SCS

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used to map major salinity changes across a field. To measure fine-scale variation between an irrigation furrow and its adjacent crop row, the small-scale insertion probe would be used.

To make the next jump in scale — for example, studying the entire state of California — Rhoades has turned to computer-aided mapping. By programming a computer to know which characteristics —such as surface topography, water table depth and cropping patterns — reinforce each other, one can in theory generate maps grading the state for regions of high and low salinity probabilities. Such maps — already under development — could prove invaluable to the Soil Conservation Service or state agencies in determining where to target their electrical-conductivity monitoring, and how planned changes in some of the mapped traits might affect a region's salinity potential.

Rhoades is also working toward the development of a technique that employs Loran-type navigation systems, used to orient ships, to identify precisely where a field sensor is taking its reading. Such accurate geographic coordinates would make it easier to build and verify the trait maps Rhoades wants to overlay. It would also make it possible to find the small volumes of soil measured earlier whenever repeat measurements must be taken.

LASERS: Other technologies are having a big impact on irrigation efficiency, or the percent of delivered water that crops actually use. And that can help control salt in several ways. First, it reduces the volume of wastewater drainage that irrigators generate — and must ultimately dispose of. More important, many farmers, like those in the upper Colorado River basin, have deposits of shale beneath their fields that contribute large quantities of salt to the field drainage passing over on its way back to a river. By reducing the "deep percolation" of their excess irrigation water, upstream users can substantially reduce the salt pollution with which downstreamers must contend. Finally, in areas where drainage is bad, reducing the excess slows the upward creep of salty water tables.

Among techniques having a big payoff in irrigation efficiency is laser leveling of fields. A revolving laser transmitter sweeps its beam across a field along a plane to which the ground will be leveled. A receiver on the field grader automatically holds the position of its scraper blade at that level. Because the laser is so precise, a field can be leveled to vary by no more than 1 inch over 100 feet.

The result is that farmers can now return to basin irrigation, one of the oldest and simplest irrigation techniques, without sacrificing efficiency of water or energy use. With basin irrigation, an entire plot is flooded rapidly for a controlled period. Lasers have increased the efficiencies of basin irrigation to 90 percent, compared with a maximum of 65 to 70 percent with standard surface irrigation, according to Allen Dedrick of the USDA Agricultural Research Service's Phoenix water lab.

DESALINIZATION: Desalting plants are being explored to lower the salt load of rivers and other waterways into which irrigation wastewater is dumped. An experimental facility in Los Banos, Calif., completed last year, is expected eventually to desalt roughly 385,000 gallons daily (a little more than 1 acre-foot). It is still undergoing start-up difficulties associated with its critical pretreatment filtering. Explains Louis Beck, chief of the San Joaquin district of California's Department of Water Resources, in Fresno, "We have done enough pilot-scale work that we think we know it's feasible to do the reverse-osmosis [desalting] process."

The principle behind these facilities involves osmotic pressure. Normally, when fresh water and salt water are separated by a semipermeable membrane, osmotic pressure will force the pure water to begin to diffuse across the membrane to dilute the salt solution. The direction of the freshwater flow can be reversed, however, if a force greater than the osmotic pressure is applied to the salty solution.

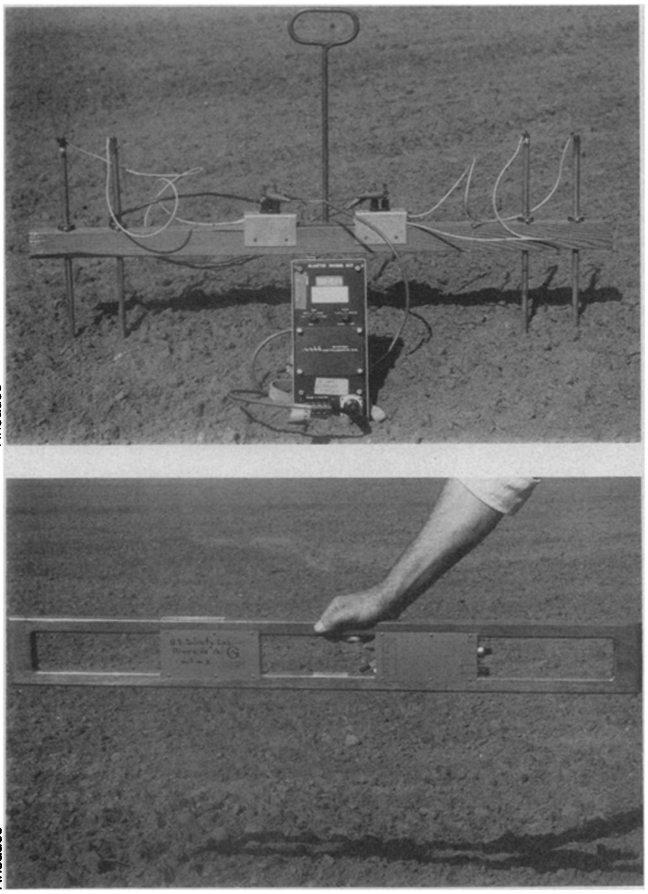
Beck points out that since any large-scale plant would be fed by miles of open drainage canals, one must expect to have to cope with dust, dirt, algae and bacteria. Unless pretreatment filtering removes all these solids, he says, the fragile reverse-osmosis membranes can be ruined. Filtering will be a primary focus of the Los Banos tests.

Desalinization is one of the costlier solutions being proposed. In fact, van Schilfgaarde and Rhoades have gone on record as saying that, while it is technically feasible, "we do not see desalting, now or in the foreseeable future, as a viable option for obtaining waters for irrigation." Beck, however, says that desalting "may be competitive" with other techniques. Depending on how the costs work out during the pilot plant's run, the state may authorize construction of full-scale facilities throughout the San Joaquin Valley. "If we can desalt water for somewhere around $300 an acre-foot and it does something to alleviate the drainage problem in the valley here, then I would almost guarantee we would go ahead and build them," Beck told Science News.

The federal government is already building the world's largest reverse-osmosis facility. Outside Yuma, Ariz., the plant will reduce salinity levels in drainage water before that water returns to the Colorado River. The $225 million facility, part of a complex package of congressionally mandated measures for reducing salt in the Colorado River, is scheduled to become operational in 1988. With a processing capacity of roughly 220 acre-feet (72 million gallons) daily, this plant is expected to desalt water at a cost of about $325 per acre-foot.

WEATHER MODIFICATION: Conceptually, cloud seeding is the most ambitious technology being considered for salinity control in the United States. Planning is under way at the Bureau of Reclamation for the Colorado River Enhanced Snowpack Test (CREST), a program aimed at increasing mountain snows and, subsequently, the flow of that river, thereby diluting its salt levels. The 1,400-mile-long river is the primary source of irrigation water for the seven western states and parts of Mexico that it serves. Cost of the eight-year experiment, for which funding has not yet been authorized, is estimated at $88 million.

At an international salinity meeting in Salt Lake City last year, the bureau's commissioner, Robert Broadbent, noted that studies his agency performed showed that cloud seeding should eventually be able to



Rhoades

Rhoades

Four-electrode insertion probe flanks its salinity readout meter (top). It's used to measure the electrical conductivity of soil, a gauge of salinity. Prototype electromagnetic-induction sensor (bottom) is used for monitoring the conductivity of larger plots. It's shown here as it would be used in its horizontal mode, resting on ground. To determine conductivity at a specific depth, user punches readings from the horizontal and vertical modes into a pocket-sized preprogrammed calculator.

reduce salinity concentrations at Imperial Dam — the last diversion before the river enters Mexico — by 100 parts per million (ppm), or by roughly one-eighth of what now exists at that point. This dilution would result from adding 2.26 million acre-feet of water annually and would yield benefits of between $9 and $12 for each $1 invested in increasing the water flow, he said.

BREEDING SALT TOLERANCE: For places where salinity cannot be reduced to levels that will support production of high cash-value crops such as produce and conventional cereals, geneticists and plant physiologists are teaming up to engineer special salt-tolerant species.

Tom Ramage began working in the area 20 years ago. "It didn't take us but 10 or 12 years to find out that we could get barley that would grow when irrigated with seawater," recalls the Agricultural Research Service scientist based in Tucson. "The problem is that you cannot get an agricultural yield from barleys that are that salt tolerant." Plants able to provide what he considers the minimum acceptable yield for most U.S. farms — 5,000 pounds per acre — just won't survive the salt stress threatening many Southwest irrigators.

Ramage says he focused his efforts on barley because it "was the first crop civilization grew on, and the way we're going it's going to be the crop that saves the world. It'll grow in more diverse conditions and produce more food per acre under adverse conditions." Moreover, he says that of all cultivated crops, "if it is not the most salt tolerant, it is certainly one of the most tolerant."

Still, because of the yield requirements of most U.S. farmers, Ramage says that at this point it "is just not economically feasible to cure the [salt stress] disease." In developing countries, however, with lower production costs (and therefore lower yield requirements), introducing salt-tolerant crops may be more rewarding. Ramage is planting the seeds for this possibility in North Africa, the Middle East and elsewhere by providing various international agencies and returning graduate students with barley seeds from some of his more salt-tolerant lines.

A more diverse effort to increase the productivity of saline soils is under way at the University of California at Davis. As part of a 10-year program the university has launched in the San Joaquin Valley, it has active breeding programs in wheat, barley and tomatoes. However, despite years of exploratory efforts in this area already, the university "has not yet released a single line of any crop to growers which has been checked out and specifically bred for salt tolerance," notes Emanuel Epstein, a plant physiologist in the program.

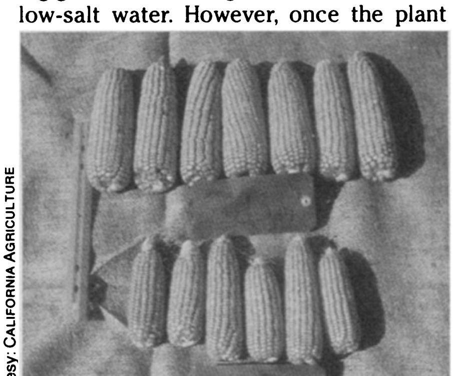
Epstein agrees with Ramage that achieving economically valuable yields has been a leading problem. But there are signs of progress. For example, university researchers have crossed a conventional salt-sensitive tomato with one native to the Galápagos islands. Though the exotic island tomato had been very salt tolerant, its fruit was bitter, yellow and about the size of a pea. The hybrid, however, has resulted in cherry-sized fruit with superior flavor and the ability to survive soils with salinity half that of seawater — roughly eight times the level at which normal tomatoes thrive. It also has a moderate yield. Tests to refine it are under way.

At the U.S. Salinity Lab, Michael Shannon is focusing on lettuce, melons and tomatoes. His goal is to exploit natural genetic variability to achieve high yield, high growth rate and high salt tolerance. Unfortunately, he says, there seems to be an unwritten rule that says the higher the growth rate, the more salt sensitive a plant will be.

DRAINAGE FOR IRRIGATION: As a short-term measure, one of the most cost-effective strategies the Salinity Lab is pursuing offers to reduce not only irrigation drainage but also the demand for "good" (low-salt) irrigation water and the immediate need to give up high cash-value crops. Though it won't solve the salt problem, this strategy could buy some farmers more time before they need the products of those ambitious plant breeders.

Irrigators ordinarily consider water having more than 2,000 ppm salt as too saline for use on crops. But Rhoades is conducting farm-scale field tests in which drainage water with 3,500 to 6,000 ppm salt — up to one-sixth the concentration of seawater — is being substituted for as much as 80 percent of the usual irrigation water, without a cut in crop yield or quality. The trick is to manage crop rotations and irrigation water quality precisely.

Plants are not uniformly sensitive to salt at all growth stages. Generally, the seedling establishment period is the most sensitive phase. In a three-crop rotation in its second year in California's Imperial Valley, wheat is planted on soil that has been leached of salt by preplant irrigation. During germination, irrigation continues with low-salt water. However, once the plant



Courtesy: CALIFORNIA AGRICULTURE

Salt-stunted corn (bottom row) is 55 percent smaller than normal for its variety.

gets to be 6 inches tall—and relatively salt tolerant — drainage water is substituted exclusively for irrigation.

"Now salinity begins to accumulate," Rhoades concedes, "but you don't create a saline soil in such a short period of time. So that allows you to grow another crop, in this case sugar beets, which are even more tolerant than wheat." Again low-salt water is used for preplant irrigation so that seedlings develop in low-salt soil. Then, when the plant is established, salty drainage is used exclusively.

Rhoades

Wheat irrigated with saline drainage gave yields that matched or exceeded those from identically managed plots irrigated with low-salt water only. Moreover, tests showed that the drainage-watered wheat made superior baking flour.

Now comes the sensitive crop in the rotation — cantaloupe. From preplant through harvest, all irrigations are with low-salt water only. "But in the process of growing this crop, you in essence reclaim the previous salinity buildup," Rhoades says. "There's enough leaching going on that you will have returned the soil to its initial state."

In another strategy, even germination-phase irrigation involves use of high-salinity water. However, because the crop bed is sloped, the salinity builds up away from the seeds. "Then we irrigate every other furrow for a while so that the dry one acts as a sink—where the water will flow towards," carrying along its salt, Rhoades explains. "After this period, we irrigate all furrows, so that we begin to get the salt moving down." And, surprisingly, at harvest time "we got the highest yields — in this case, significantly higher yields—with the more drainage water that we substituted for low-salt water," he says.

The U.S. Salinity Lab has spent much time over the last six years testing experimental rotations and watering strategies in the Imperial and San Joaquin valleys, Rhoades says, so that farmers may see firsthand that these strategies require no radical changes in their practices. "No one wanted to think that you could use water like this several years ago," he says. "What we're showing is that it's easy. You just have to know your crops and the right orders in which to sequence things."

Clearly, soil salinity will not go away. But as these research endeavors illustrate, serious inroads are being made to control the problem so that farmers can at last learn to live with the salt of their earth. □

Salt stress

Anyone who has a houseplant growing in a pot without drainage holes is subjecting that plant to salt stress. Over time, salt entering with tap water will build up in the soil. The first evidence will be white crystals on the soil surface —often hugging the inner rim of the pot. As time goes on, the plant's growth will slow; when the salt levels get high enough the plant simply dies. Farmers who irrigate risk the same soil salinity buildup.

Though a plant encounters dissolved ions of many different salts (including sodium, magnesium, calcium, chloride, sulfate and carbonate), most plants do not differentiate among the specific salts that have dissolved in the soil water, and instead respond to salinity only on the basis of that water's osmotic potential.

Water tends, by osmosis, to go from a region where the concentrations of dissolved substances — such as salt — are low to one where the concentrations are high. So, in soils that are highly saline, water in the plant tissues tries to migrate into the soil. "We call this osmotic stress," explains Emanuel Epstein, a plant physiologist with the University of California at Davis. To keep itself from becoming lethally dehydrated, a salt-stressed plant must undertake osmotic adjustment.

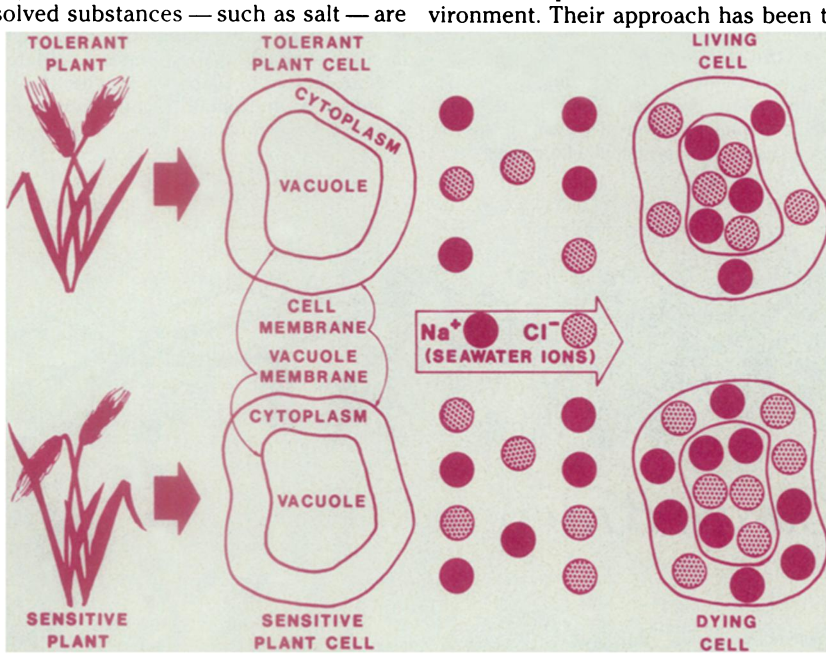
"As a broad generalization, we look upon plants as being either *halophytes,* from the Greek, meaning salt plants, or *glycophytes,* meaning sweet-water plants," Epstein says. Each has its own approach in adjusting to osmotic stress.

Halophytes survive salty environments, he says, "by fighting fire with fire. They absorb salt and use it as an osmotic regulator" to help balance the concentration of dissolved substances within the water in their tissues to that of their external soil-water's environment. However, Epstein says, even halophytes cannot tolerate much salt in their intracellular cytoplasm, that small region where metabolic activity is centered. So it's into each cell's internal waste-disposal site—the vacuole — that most salt is dumped and where most salt-mediated osmotic regulation occurs. This dump zone can usually handle most of the osmotic adjustment a halophyte requires.

For the salt-sensitive glycophytes, including virtually all crop plants, osmotic adjustment is more taxing. A membrane surrounds each plant cell, regulating the traffic of molecules in and out. In glycophytes, these membranes are fairly effective at excluding salt ions. Therefore, glycophytes must find solutes other than captured soil salts to balance internal osmotic pressures to the outside environment. Their approach has been to use organic compounds such as sugars, amino acids and organic acids — substances the plant manufactures.

But this strategy is a costly one, Epstein says, noting that "the plant has to expend considerable metabolic energy, which it gets by photosynthesis, to make these organic soluble substances." He adds that "if a plant has to expend its organic substances for the purpose of keeping water moving from the outside in, then it has less to grow on."

Now being sought in a number of labs throughout the country is a detailed understanding of how plants — especially salt-tolerant glycophytes — have adapted biochemically to survive moderate levels of salt. —*J. Raloff*



Los Alamos National Laboratory

Glycophytes die when they lose the ability to control cytoplasm salt-ion levels.