tions from other halocarbons even though these are a source of concern. The use of chlorodifluoromethane ($CHClF_2$), particularly in refrigeration, has increased 25 percent in the past 2 years, and the production of methylchloroform (CH_3CCl_3), widely used as a degreasing solvent, is doubling every 5 years. These chemicals are less inert than CFM's and are largely destroyed in the lower atmosphere, but significant quantities can make their way to the stratosphere. Atmospheric measurements, the panel says, now indicate that methylchloroform contributes between a quarter and half as many chlorine atoms to the stratosphere as either trichlorofluoromethane or dichlorodifluoromethane. If its usage continues to grow, it may become the largest single source of stratospheric chlorine. Once in the stratosphere, methylchloroform is not as effective as the CFM's in destroying ozone, but the differences are so small that the continued growth of its production remains a major cause for alarm.

—THOMAS H. MAUGH II

Plants: Can They Live in Salt Water and Like It?

Finding out how plants cope with stresses such as salt and drought may eventually permit the development of more resistant strains

Irrigation of farm crops is turning out to be something of a mixed blessing. It permits farming in climates that would otherwise be too dry to support agriculture. But in many areas irrigation is leading to the degradation of the soil because of the deposition of such high concentrations of salt that plants can no longer be grown there. "Salinity is now recognized as a significant problem in one-third of all irrigated land," said Jack Norlyn of the University of California, Davis, at a recent conference* dealing with plants and how they cope with environmental stress.

The conference participants focused mainly on the interrelated stresses of salinity and drought. Many agricultural scientists think that arid and semiarid lands may be the best bet for increasing our supply of arable land. "The arid and semiarid regions impose the worst stress," says Emanual Epstein, also of Davis, "but they are the most promising regions for increasing our production of food and fiber." The soil is often fertile, sunlight is plentiful, and the growing season is long. The only thing that prevents many deserts from blooming is lack of water.

Irrigation can solve that problem—provided a supply of fresh water is available—but the solution is only temporary unless the irrigation is very carefully managed to prevent accumulation of salt. For example, the water delivered each year in California, 90 percent of which ends up on agricultural lands, contains 10 million tons of salt, according to James Walsh of the California Department of Water Resources. Moreover, the situation is often aggravated by the fact that many arid soils have a high salt content to start with.

Unless drainage is provided to carry off the irrigation water, the water with its dissolved salt sinks deep into the soil. Then, if the water table rises, as it periodically does, the salt is carried back to the surface, where it can reduce plant growth and crop productivity. Evaporation of irrigation water also contributes to the salinization process. The increasing salinity of the San Joaquin Valley of California is already costing the farmers there $32 million per year in reduced crop yields.

The problem of dry or saline soils might be circumvented if plants more tolerant of these conditions could be developed, although some agricultural scientists have questioned the wisdom of this approach. In their view, better management of irrigated lands to prevent salt deposition and reclamation of lands where it is already a problem are preferable. But, as Norlyn points out, development of salt-tolerant plants might permit expansion of agriculture into lands that are not now usable because of their high salt content. He suggests that barley would be an especially good candidate for such improvement because it is already relatively salt-resistant and a small improvement may make it possible to grow barley in currently marginal lands. The increasing demands of a growing world population for food and energy may necessitate an expansion of arable land, especially if biomass, which is plant material, ever becomes an important energy source.

The methods under consideration for developing salt-tolerant plants range from the commonplace, those using established practice to select and breed plants capable of thriving in salty environments, to the exotic, namely, genetic engineering. Some observers thought that the conference title, which stressed the genetic engineering of osmoregulation, was premature, if not presumptuous, however. (The term osmoregulation denotes the strategies that plant and bacterial cells may adopt to prevent the water loss, a cellular injury caused by some stresses, including salinity, drought, and cold.)

Any scientist who wants to be a genetic engineer must first catch the appropriate genes. And plant researchers have yet to do that for osmoregulation. As C. Barry Osmond of Australian National University in Canberra put it, "As far as genetic engineering goes, we do not know what we want to engineer at the moment."

This criticism notwithstanding, the conference participants pointed to some recent developments that lead them to believe that they are on the right track. For example, László Csonka and Raymond Valentine of the University of California, Davis, have generated a mutation that confers salt tolerance on bacteria.

When bacteria, or plants for that matter, that are not tolerant to salty conditions are placed in an environment with a high salt concentration, their cells tend to lose water. This happens because the water concentration inside the cells is higher, or the osmotic pressure lower, than that outside. Consequently, water flows out of the cells down the concentration gradient.

Some plants—those that live in the sea

*Symposium on Genetic Engineering of Osmoregulation: Impact on Plant Productivity for Food, Chemicals, and Energy, held at Brookhaven National Laboratory, Upton, New York, 4 to 7 November 1979. The symposium was sponsored by the National Science Foundation and the Department of Energy.

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or along marshy coasts, for example—are not only tolerant of salty conditions but thrive in them. They have evolved ways to cope with the salt-induced stress. According to Epstein, many of these plants compensate for high external salt concentrations by increasing the concentrations of dissolved materials within their cells. They can do this either by taking up salts or other solutes from the environment or by synthesizing soluble organic compounds.

Bacteria may use some of the same strategies. *Salmonella typhimurium*, the bacterium studied by Csonka and Valentine, can adapt to salt by accumulating the amino acid proline from the medium in which it is incubated. A high-salt medium that does not contain proline inhibits the growth of the bacteria, but they multiply faster in a high-salt medium containing it.

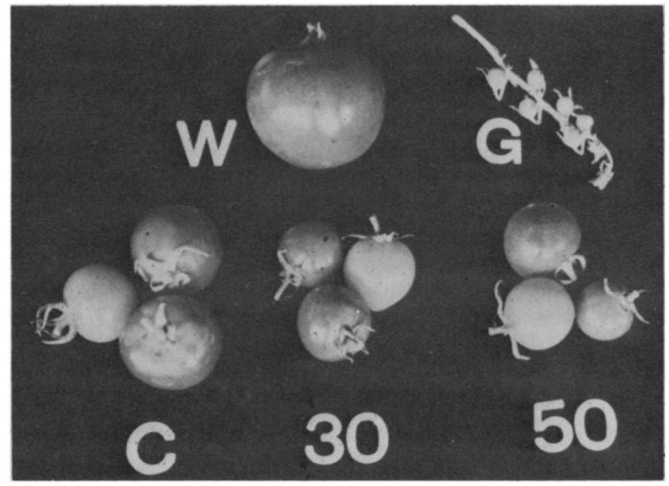
These findings led the Davis workers to hypothesize that bacteria capable of producing large quantities of proline for themselves would be more resistant to salt than those without the ability. This hypothesis was supported when Csonka and Valentine isolated a mutant bacterium that both produces large quantities of the amino acid and grows well in solutions with high salt concentrations.

In this case, the genes for the overproduction of proline were carried on a plasmid, a piece of DNA that replicates independently of the bacterial chromosome. This plasmid can be transferred among related bacteria. As a result of the transfer, the recipient strain acquires the characteristics of proline overproduction and increased salt tolerance.

Encouraged as they may be by this evidence for the genetic transmission of salt tolerance, the investigators are still some way from having the gene (or genes) in hand. Meanwhile, the plant breeders are attempting to develop salt-resistant plants by more conventional methods. Their biggest problem at the moment is lack of a fast, easy method for selecting plants with the desired characteristic. Currently, the only way to tell for sure whether a plant strain is resistant to salt is to grow it in salty conditions and see what happens, a time-consuming and expensive process.

A promising technique now under investigation in a number of laboratories may speed up the process, however. It requires that suspensions of plant cells be grown in culture.

The technique is analogous to the methods used to select bacterial mutants, according to D. William Rains of the University of California, Davis. "The advantage," says Rains, "is that you have a lot of 'individuals' and thus variability in each culture." The culture medium can be adjusted to select for the desired trait. For example, a high salt concentration can be used to identify cells that can survive this stress. The major problem limiting the application of the method is the requirement for regenerating whole plants from individual cells, although during the past few years investigators have learned how to regenerate a number of plant species, including such important crop plants as alfalfa, rice, wheat, and cotton.



Hybrid tomatoes produced by crossing Galápagos tomatoes (G) *with the Walters tomato* (W), *a common strain grown in California. The bottom row shows some of the hybrids grown under normal conditions* (C), *and in 30 and 50 percent seawater.* [*Source: Jack Norlyn, University of California, Davis*]

In one experiment, Rains and his colleagues used the culture technique to select salt-tolerant alfalfa cells and then regenerated whole plants. They are now in the process of growing enough of the plants in the laboratory so that the alfalfa can be tested in the field for salt resistance.

Another goal of the researchers is uncovering a biochemical marker that is invariably associated with tolerance. This would permit selection of salt-tolerant plants without requiring that they be grown in the field.

The compounds used by salt-resistant plants to compensate for high osmotic pressures in the environment are among the possible markers studied by researchers. So far, investigators have identified only a relatively limited number of these compounds, according to Robert Jefferies of the University of Toronto. They include amino acids such as proline and glycine, polyols (compounds with three or more hydroxyl groups) such as glycerol and sorbitol, and derivatives of betaine, a substituted ammonium compound.

Included in the evidence implicating these substances in salt tolerance, said R. Garrett Wyn Jones of University College, North Wales, is their distribution. They are usually found, often in high concentrations, in plants known to thrive in salty environments. Moreover, their concentrations inside the plant cells increase as the external salt concentrations increase. But so far at least, the accumulation of these substances by crop plants, such as barley, is not a good marker for tolerance, according to Jones.

For the time being, plant scientists are forced to rely on the classical methods for breeding and selecting plants, slow though these methods may be. Still, a number of experiments are under way. Norlyn described an effort by his group to breed a salt-tolerant tomato, using a tomato species discovered growing by the sea on one of the Galápagos Islands. The Galápagos plant, although capable of growing in land washed by seawater, produces only an inedible, pale orange fruit, roughly the size of a child's fingertip. The hybrid progeny of crosses with a common California tomato produce a red fruit that looks like a cherry tomato. According to Norlyn, 67 percent of the hybrid plants survive in 70 percent seawater and 15 percent yield tomatoes in those conditions.

Perhaps the most ambitious goal of the researchers involved in these studies of plant stress is to develop crops that can be irrigated with seawater. This would permit agriculture in areas such as the Middle East and the coastal deserts of Africa and South America, where seawater is plentiful but fresh water scarce. No one thinks that the realization of that goal will occur any time soon. One conclusion stood out at the conference: there is still a great deal to be learned about how plants adapt to salinity and other stresses. Nevertheless, investigators think they now have some promising leads that may ultimately allow expansion of the world's tock of arable land.—JEAN L. MARX