for three weeks to nutrient solutions containing either sodium chloride or sodium sulfate, as well as to control (no salinity) solutions. The two sodium salts were added at concentrations that reduced the water potential of the solutions to the same extent (0.2 MPa). When compared with control plants in the absence of salinity, growth of grain sorghum was inhibited dramatically by sodium sulfate but much less by sodium chloride. Specifically, sodium chloride reduced the shoot weight to 70 percent of that of the control, whereas sodium sulfate dropped it to 43 percent. Thus, grain sorghum appears to be more sensitive to sulfate than to chloride salinity although, overall, it is considered to be relatively salt-resistant.

The examples described thus far emphasize a variety of ion-specific effects in plant responses to salinity. Additional support for the hypothesis that, in many glycophytes, salinity inhibits growth and performance of the plant mainly through ion effects comes from studies in which the water relations of the plant were also examined. With graduate student R. W. Kingsbury, E. Epstein and R. W. Pearcy found that two wheat lines differing in salt resistance differed minimally in water relations but substantially in their relative growth rates and photosynthesis. These results suggest that the primary difference was in the response of the two lines to specific ion effects.

A study being conducted by graduate student P. S. C. Curtis, A. Läuchli, and F. E. Robinson indicates a similar response to salinity in the stem-fiber plant kenaf. The plants were grown at the Imperial Valley Field Station (irrigation with Colorado River water, EC=1.7 dS/m, or 1,100 mg/L salt) and in the desert east of the station (irrigation with groundwater, EC=2.8 dS/m, or 1,800 mg/L salt). Growth at the desert site was severely reduced. Leaf water potentials and other measures of water-relations did not differ significantly between the two sites, but irrigation with groundwater greatly increased concentrations of chloride and sodium in the leaves. As in wheat, growth reduction in kenaf does not appear to be caused by salinity-induced water stress but is more likely due to ion effects.

Conclusions

Although our knowledge of the mechanisms of salt tolerance and sensitivity in plants is still scant, we are beginning to understand some of the fundamental differences between halophytes and glycophytes. Crops (mostly glycophytic) are comparatively salt-sensitive, salinity causing osmotic and ion-specific effects leading to reduction in growth and yield. Much research in the past has put emphasis on the osmotic effects of salinity, whereby the availability of water to the plant is diminished. Our research, however, leads to the conclusion that specific ion effects deserve at least "equal billing" as the cause of salt-induced reduction in the growth of crops.

We need to identify physiological markers related to salt resistance that may be used in genetic improvement of crops for high productivity in salt-affected soils. Physiological studies with genetic lines differing in salt resistance and investigations comparing cultivated species and wild, salt-tolerant relatives will help in achieving this goal.

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Crop tolerance

Eugene V. Maas

One strategy available to farmers with saline soils is to select salt-tolerant crops. Crop tolerance to salinity ranges widely from the very salt-sensitive bean to the highly tolerant barley and cotton.

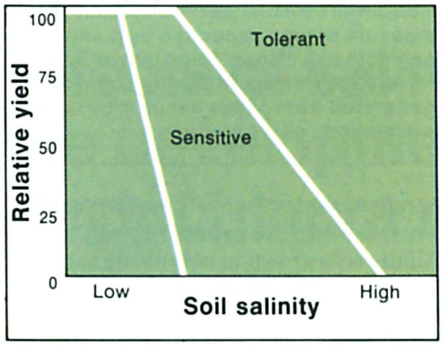
The U.S. Salinity Laboratory in Riverside has been testing the salt tolerance of crops since it was established in 1937. It now has data on nearly 70 crops, which will be useful in predicting responses on saline soils (see table). Experiments recently completed or in progress will provide additional data on asparagus, bread wheat, durum wheat, triticale, sorghum, sugarbeet, and guayule. Five or six crops can be tested simultaneously at facilities in Riverside and Brawley, and often more than one crop per year can be tested in a given set of plots. Crops are occasionally tested on field sites, as was done with corn in the Sacramento-San Joaquin Delta *(California Agriculture,* July-August 1983) and as is under way with plums at the Kearney Agricultural Center, Parlier.

Salt tolerance tests are usually conducted in small experimental plots, where commercial practices are followed as closely as possible, with adequate moisture and fertility. To ensure an acceptable stand, researchers plant seed in a nonsaline seedbed and impose salinity by adding calcium and sodium chloride salts to the irrigation water after the seedlings have emerged. They test several salinity levels to determine both the threshold level that begins to decrease yield and the rate of yield reduction caused by higher levels. Generally, the higher the threshold level, the less yield is decreased as salinity increases.

Because numerous plant, soil, and weather conditions also affect crop growth, yield must be expressed as a percentage of that obtained under similar but nonsaline conditions. Actual yields vary from location to location and year to year, but the relative yield reductions caused by salinity remain reasonably consistent.

Soil salinity in the plant root zone is conveniently measured as electrical conductivity, which is directly proportional to the salt concentration in the soil water. Two commonly used methods pro-

Small plots of wheat are used to determine salt tolerance. Salts are added to irrigation water after seedlings have emerged to determine the point at which salt damage begins to appear and the rate of yield reduction.



The more salt tolerant a crop is, the less yield decreases as salinity rises.

vide reliable measurements: one involves sampling the soil within the root zone, preparing a saturated extract, and measuring the electrical conductivity of the extracted soil water; the other uses a recently developed instrument that, when inserted into the soil, directly measures the electrical conductivity of the soil water. Since soil salinity usually increases with depth, measurements are taken at several depths within the root zone, and the values averaged.

Salinity may also vary throughout the season, often increasing with time. Although most crops become more tolerant at later stages of growth, there are some exceptions. For example, salt seems to affect rice during pollination and may decrease seed set and grain yield. Plants are generally most sensitive during the seedling and early vegetative stages of growth. The U.S. Salinity Lab is conducting experiments on the relative sensitivity of several crops at different stages of development. In sweet corn, for example, it was found that, although seedling growth was reduced by salinity, the salt level of the irrigation water could be increased up to about 9 dS/m (5,800 mg/L) during the tasseling and grain-filling states without affecting yield.

Because of the greater sensitivity at seedling emergence, it is imperative to keep salinity levels in the seed bed as low as possible at planting time. If salinity levels reduce plant stand, potential yields may be decreased far more than predicted by salt tolerance data.

Salt tolerance information usually applies to crops irrigated by surface methods, such as furrow or basin-type flooding. Sprinkler-irrigated crops are subject to damage by both soil salinity and salt spray to the foliage. Salts may be directly absorbed by the leaves, resulting in injury and loss of leaves. In crops that normally restrict salt movement from the roots to the leaves, foliar salt absorption can cause serious problems not normally encountered with surface irrigation systems. For example, water with about 4.5 dS/m (2,900 mg/L) salts reduced the yield of peppers by over 50 percent when sprinkler-applied, but only 16 percent when applied to the soil surface.

Unfortunately, no information is available to predict yield losses as related to salinity levels in sprinkler irrigation water. Greenhouse experiments conducted at the U.S. Salinity Lab to test the susceptibility of various crops to foliar injury from saline sprinkling waters indicate that tolerance is related more to the amount of salt absorbed by the leaves than to their tolerance to soil salinity. The degree of injury depends on weather conditions and water stress. For instance, leaves may contain excessive levels of salt for several weeks without any visible injury symptoms and then become severely burned when the weather becomes hot and dry.

It is reasonable to assume that saline irrigation water will reduce yields of sprinkled crops at least as much as those of surface-irrigated crops. Additional reductions in yield could be expected for crops susceptible to sprinkler-induced foliar injury.

Unlike most annual crops, tree fruit crops are sensitive to specific salt constituents and often develop leaf burn symptoms from toxic levels of sodium or chloride. Different varieties and rootstocks accumulate these ions at different rates, and so each one must be evaluated individually. Because it is difficult to obtain such data on producing trees, the figures are usually based on vegetative growth of young trees rather than on yield; consequently, they provide only general guidelines.

Salt tolerance ratings cannot provide accurate estimates of actual crop yields, which depend on many other growing conditions, including weather, fertility, soil type, water stress, insects, and disease. The ratings are useful, however, in predicting how one crop might fare relative to another on saline soils under different cultural conditions. As such, they are valuable aids in managing salinity problems in irrigated agriculture.

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Salt tolerance of agricultural crops

Crop	Maximum soil salinity without yield loss (threshold)*	% Decrease in yield at soil salinities above the threshold
Sensitive crops	*dS/m*	*% per dS/m*
Bean	1.0	19
Carrot	1.0	14
Strawberry	1.0	33
Onion	1.2	16
Almond†	1.5	19
Blackberry	1.5	22
Boysenberry	1.5	22
Plum; prune†	1.5	18
Apricot†	1.6	24
Orange	1.7	16
Peach	1.7	21
Grapefruit†	1.8	16
Moderately sensitive crops		
Turnip	0.9	9.0
Radish	1.2	13
Lettuce	1.3	13
Clover, berseem	1.5	5.7
Clover, strawberry	1.5	12
Clover, red	1.5	12
Clover, alsike	1.5	12
Clover, ladino	1.5	12
Foxtail, meadow	1.5	9.6
Grape†	1.5	9.6
Orchardgrass	1.5	6.2
Pepper	1.5	14
Sweet potato	1.5	11
Broadbean	1.6	9.6
Corn	1.7	12
Flax	1.7	12
Potato	1.7	12
Sugarcane	1.7	5.9
Cabbage	1.8	9.7
Celery	1.8	6.2
Corn (forage)	1.8	7.4
Alfalfa	2.0	7.3
Spinach	2.0	7.6
Trefoil, big	2.3	19
Cowpea (forage)	2.5	11
Cucumber	2.5	13
Tomato	2.5	9.9
Broccoli	2.8	9.2
Vetch, common	3.0	11
Rice, paddy‡	3.0§	12§
Squash, scallop	3.2	16
Moderately tolerant crops		
Wildrye, beardless	2.7	6.0
Sudangrass	2.8	4.3
Wheatgrass, std. crested	3.5	4.0
Fescue, tall	3.9	5.3
Beet, red‡	4.0	9.0
Hardinggrass	4.6	7.6
Squash, zucchini	4.7	9.4
Cowpea	4.9	12
Soybean	5.0	20
Trefoil, birdsfoot	5.0	10
Ryegrass, perennial	5.6	7.6
Wheat, durum	5.7	5.4
Barley (forage)‡	6.0	7.1
Wheat‡	6.0	7.1
Sorghum	6.8	16
Tolerant crops		
Date palm	4.0	3.6
Bermudagrass	6.9	6.4
Sugarbeet‡	7.0	5.9
Wheatgrass, fairway crested	7.5	6.9
Wheatgrass, tall	7.5	4.2
Cotton	7.7	5.2
Barley‡	8.0	5.0

NOTE: These data serve only as guidelines to relative tolerances among crops. Absolute tolerances vary, depending on climate, soil conditions, and cultural practices. **SOURCE:** Maas, E. V. 1984. Salt tolerance of plants. *In* Handbook of Plant Science in Agriculture. (ed.) B. R. Christie. CRC Press Inc., Boca Raton, Florida. (in press) *Soil salinity expressed as electrical conductivity of saturated soil extracts. 1 decisiemens per meter (dS/m) = 1 millimho per centimeter (mmho/cm). 1 dS/m = approximately 640 mg/L salt. †Tolerance is based on growth rather than yield. ‡Less tolerant during emergence and seedling stage. §Values for paddy rice refer to the electrical conductivity of the soil water during the flooded growing conditions.