

long, were harvested from the center of each replicate early in October each year.

In sprinkled plots, mini-sprinklers applied an average depth of 16 mm over the entire plot area in one hour (see table). Water was applied in the sprinkled plots at about twice the expected rate of evapotranspiration (ET) to keep the salinity profile in the root zone as uniform as possible. Sprinkler irrigations were applied weekly except for a few brief periods early in the season when light, frequent irrigations were applied for plant stand establishment.

Irrigation water for the subirrigated plots was blended directly in the pipelines by manually adjusting gate valves, so that all four treatments could be irrigated simultaneously to minimize soil water movement among plots. Each subirrigation plot was irrigated by filling two ditches spaced every 16 rows of corn. In 1980 and 1981, the rate of flow entering and leaving each ditch was monitored with orifice plates.

The subirrigated treatments were similar to irrigation practices of the area. Two or three subirrigations were applied during each season. Each subirrigation continued for several days and ended when the water table rose to within about 15 cm of the soil surface midway between the irrigation ditches.

Results

Statistical analysis of grain yield in relation to soil salinity in the root zone for each treatment during each year showed very little difference between irrigation methods in either threshold or slope (rate of yield reduction at salinity values larger than the threshold) (fig. 2). Based on the results, the salt tolerance of corn harvested as grain has a threshold of 3.7 dS/m and a slope of 14. The threshold is close to the value of 3.4 calculated from previously published tolerance data, but the rate of yield reduction is considerably greater than the value of 6 obtained in other areas. □

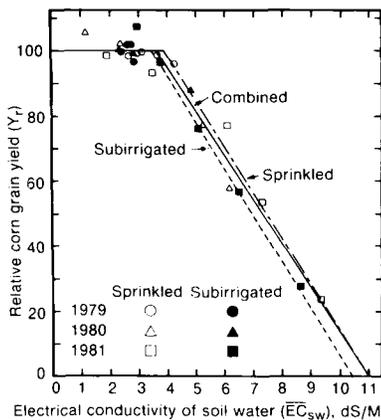


Fig. 2. Salt tolerance as indicated by yield showed little difference between irrigation methods in either threshold or slope.

Relationship of irrigation water salinity and soil water salinity

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Significant concentrations of soluble salts are not normally found in organic soils. Organic soils, differentiated from mineral soils by an organic matter content greater than 20 percent, are formed from partially decayed plant remains that accumulated originally in shallow bodies of fresh water or in poorly drained areas where anaerobic conditions persisted. In contrast, saline soils usually occur in regions where water is lacking. The Sacramento-San Joaquin Delta is an important example of an agricultural area with organic soils that are threatened by salinity.

The objective of this study was to establish the general relation between salinity of the irrigation water and soil water salinity for the organic soils of the Delta, based on results from the three-year field experiment to establish the salt tolerance of corn. An initial step was to standardize procedures of measuring soil salinity in organic soils. Previous work indicated that the method of sample preparation influenced the measurement of electrical conductivity (EC) in organic soils, particularly in subsoil samples.

Salinity measurements

Soil salinity is determined routinely by measuring the electrical conductivity of a soil saturation extract. The soil sample is either dried, ground, and passed through a 2-mm round-hole sieve or passed through a sieve without drying or grinding. Water is then added while mixing until the soil is saturated. The mixture is allowed to stand overnight, and additional water is added if required to saturate the sample. The soil solution extracted by vacuum from the saturated soil is then measured for electrical conductivity.

In September 1979, we took soil samples from each experimental plot and divided them into three subsamples before analysis. One set of subsamples was allowed to dry at room temperature and then ground (dry, ground). A second set

was dried at room temperature but was not ground (dry, unground). The third was brought to saturation without drying or grinding (wet, unground).

The influence of sample preparation on the measurement of salinity is illustrated in figure 1 for samples taken from the treatments with applied waters having an electrical conductivity of 2 dS/m (about 1300 ppm) in the two methods tested: subirrigation and mini-sprinklers. Sample preparation had no significant influence on the measurement from samples collected above a depth of

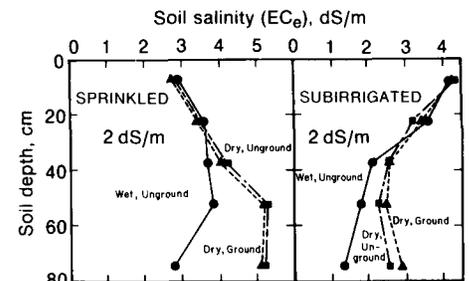


Fig. 1. Sample preparation technique influenced electrical conductivity of soil saturation extract (EC_e) below 30 cm.

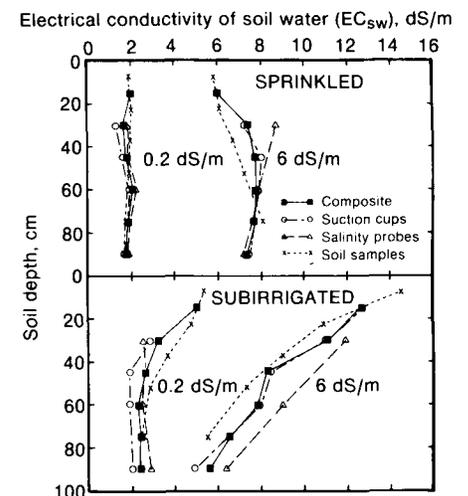


Fig. 2. Measurements (1981) from wet, unground soil samples agree closely with other measures of salinity.

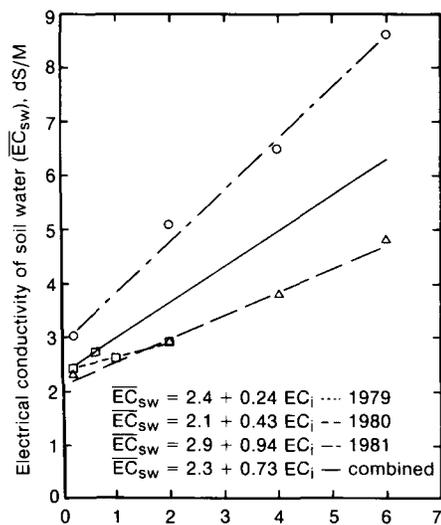
30 cm. Below 30 cm, significant differences occurred between dried and undried samples. Grinding had little influence on the results. Drying the sample before analysis also increased measured values of ion concentration significantly above values of undried samples obtained from below a depth of 30 cm.

To determine which preparation technique correlated best with other measures of salinity, we compared the results with soil salinity values obtained by vacuum extraction of soil water directly with porous-ceramic suction cups and measuring its electrical conductivity and by measuring soil water conductivity with four-electrode salinity probes (figure 2). Measurements from wet, unground soil samples agree well with the other measures of soil salinity.

Water quality and soil salinity

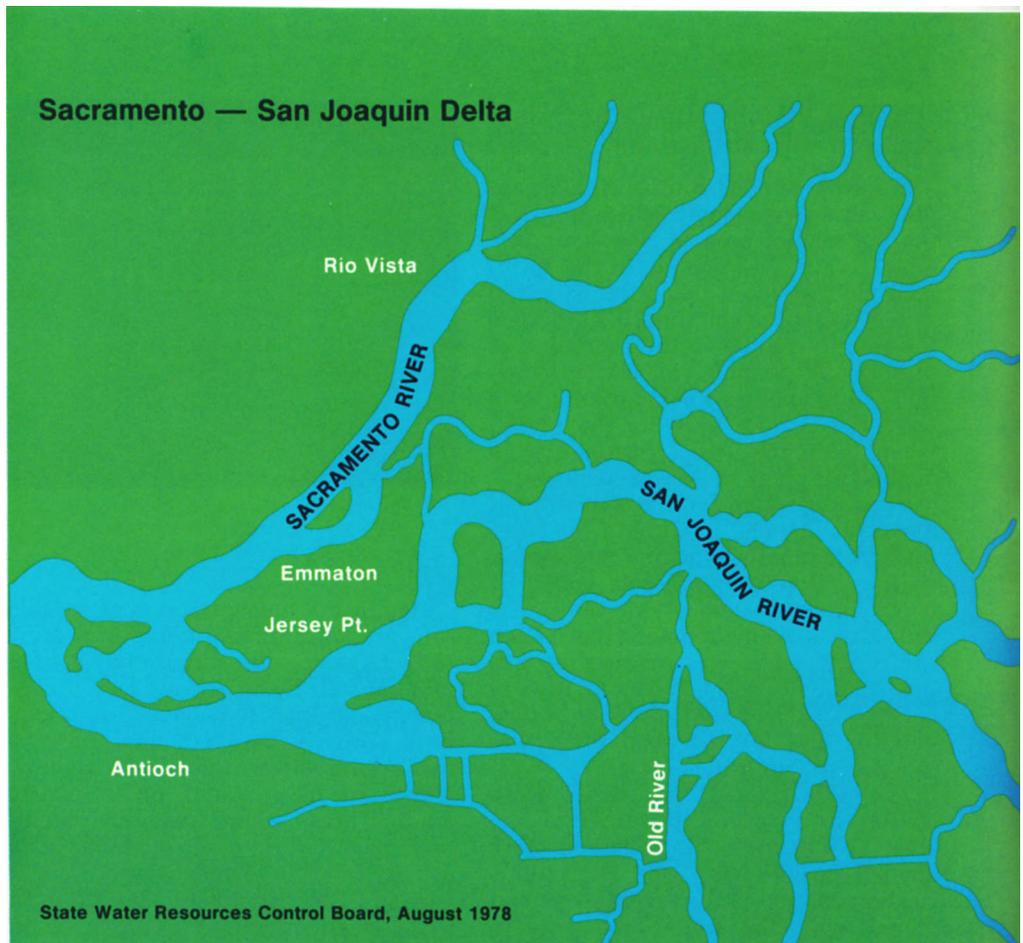
Irrigation water quality has a dominant influence on soil salinity, but winter rainfall, soil properties, leaching practices, irrigation techniques, and the elevation and salt concentration of a water table can significantly affect the relationship. The relation between the electrical conductivity of the irrigation water and the average electrical conductivity of soil water in the root zone for the subirrigated portion of the field experiment is given in figure 3 for each year of the study. The relationship in the sprinkled treatments was similar, but the data are not presented here.

We used an average soil water conductivity for each soil depth, monitored by suction cups, four-electrode salinity probes, and soil samples, to determine a composited average for each 15-cm soil increment through the root zone to a



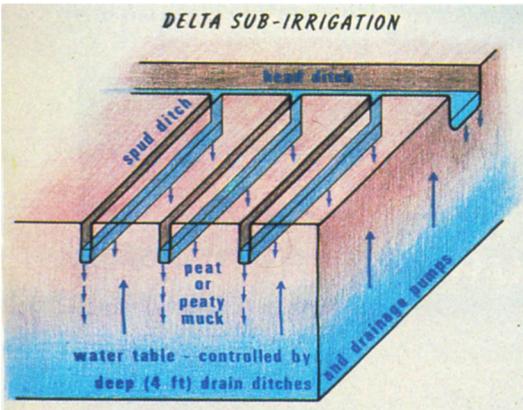
Electrical conductivity of irrigation water (EC_i), dS/m

Fig. 3. Average salinity in root zone under subirrigation rose at a lesser rate than salinity of irrigation water.



Greenhouse tests at U.S. Salinity Laboratory at Riverside showed that corn is most sensitive to high salinity of irrigation water during the vegetative growth stage and most tolerant at the germination stage. Salinity had to exceed 4500 ppm before germination was reduced.





Thirty of the Delta test plots were irrigated with mini-sprinklers (far right). The other 16 were irrigated by the usual local method of subirrigation, in which water from the river channel is siphoned over the levee and into a system of "spud ditches" 6 inches wide, 10 to 24 inches deep, and spaced from 40 to 80 feet apart (right). Spud ditches cut through a cornfield by a trencher are filled several times during each irrigation season.



Yields of corn grain from plots sprinkler-irrigated with 8 dS/m water (lower row) were 55 percent less than the yield from plots irrigated with nonsaline water.



Behind Eugene Maas is corn that was irrigated with nonsaline water. Corn in the foreground was irrigated with 8 dS/m water (about 5100 ppm).



depth of 90 cm. We then averaged these composite values to establish the mean soil water electrical conductivity.

Differences among data for the three years were larger than differences between irrigation methods. This was caused, in large part, by differences in rainfall and management of the water table depth during the winter. Soil salinity early in the growing season was significantly lower than later in the season.

Of paramount concern in the organic soils of the Delta is the change in the relation between salinity of irrigation water and of soil water as irrigation water salinity increases. For 1981, the year when irrigation water salinity had the greatest influence on soil water salinity, the rate of change was 0.94 for subirrigation (fig. 3), and 0.95 for sprinkled treatments (not shown). Thus, the relation between soil water and irrigation water salinity was less than 1:1 for every year of the study and for both irrigation methods. In other words, increasing the salinity of irrigation water above 0.2 dS/m (about 130 ppm) should only increase average soil salinity in the root zone by a like amount if winter rainfall is normal (about 400 mm) and irrigation, leaching, and groundwater control practices are similar to those for the subirrigated treatments of the field experiment. From the relationship given in figure 3 for the combined subirrigation data, the electrical conductivity of the irrigation water that accompanied the threshold value of soil water salinity for corn grain (3.7 dS/m) would be 1.9 dS/m. For below-normal rainfall as in 1981, electrical conductivity of irrigation water at the threshold value for grain would be 0.8 dS/m.

In an environmental impact report on the Delta by the State Water Resources Control Board in 1978, average soil water salinity was reported to be about eight times greater than the salinity of the irrigation water in a number of fields in the Delta where irrigation water salinity probably averaged 0.3 dS/m. Thus, the expected average soil water salinity based on the earlier report would be just over 2 dS/m, which is essentially the average value we found in this field trial when irrigation water salinity was 0.2 dS/m (fig. 3). Based on the results of the field trial, however, the ratio is not constant; the factor decreases as irrigation water salinity increases.

Summary

In these studies, we found that above-average rainfall and maintaining the water table about 1 meter below the surface effectively leached the upper soil profile. Under present conditions of low salinity in the irrigation water and

with normal winter rainfall, soil salinity is about 8 times greater than the salinity of the irrigation water. As the salinity of the irrigation water increases, however, the factor 8 becomes substantially smaller. At the soil water salinity threshold for corn grain (3.7 dS/m), the factor is 2.3 for subirrigation, which

results in a maximum value of 1.9 dS/m (about 1,200 ppm) for the salinity of the irrigation water without yield loss under normal conditions. With subirrigation and below-normal rainfall as in 1981, the maximum salinity of the irrigation water without yield loss would be 0.8 dS/m (about 500 ppm). □

Salt sensitivity of corn at various growth stages

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As a followup to the field test of salt tolerance of corn, we attempted to determine in greenhouse studies the salt sensitivity of corn at various growth stages. If corn is more sensitive during one stage than another, the salinity of the irrigation water could be regulated during the season to minimize salt injury during the more sensitive stage. Standards are needed, particularly during droughts and during the later part of the growing season when the water supply may be limited.

The objectives of this study were to determine: (1) the sensitivity of corn to soil salinity during germination, emergence, and seedling growth stages and (2) how rapidly and to what extent the salinity of the irrigation water can be increased during the cropping season without decreasing yield.

Experimental procedures

We measured germination in covered 9 x 9 cm germination dishes containing 20 corn seeds buried to a depth of 1 cm in presalinized organic soil. Sixteen cultivars were tested at eight levels of soil salinity with four replications. Germination dishes were kept in the dark at a constant temperature of 22°C. Germination counts were made daily over a period of two weeks.

In the emergence and seedling experiment, corn was grown in the greenhouse in 55-liter plastic pots filled with Rindge muck topsoil obtained from near Terminous, California. Treatments consisted of six irrigation waters having electrical conductivities of 0.2, 1, 3, 5, 7, and 9 dS/m, with each replicated 12 times. Each replication contained four pots with a different cultivar in each

pot. Four corn cultivars were planted in each of four separate trials. Nine cultivars — seven field corn and two sweet corn — were tested. Pioneer 3780 was grown in each trial as a benchmark cultivar. At one, two, and three weeks after planting, we harvested plants to measure dry matter production.

In the experiment on increasing salinity during the growing season, Bonanza, a sweet corn cultivar, was grown in the same pots used in the preceding experiment. The experiment consisted of 18 treatments, each replicated four times with four pots per replication. The same six saline waters were also used in this experiment.

The first six treatments were irrigated throughout the experiment without changing the salinity of the irrigation water during the season, as is typical of a salt tolerance trial. The remaining 12 treatments were designed to determine the maximum salinity in the root zone that corn could tolerate at three growth stages during the season without a loss in yield. The salinity of the irrigation water in these treatments was increased by different amounts after 30 or 60 days. The three 30-day periods represent the vegetative, tasseling, and grain-filling stages during the growing season.

Results

Germination tests in salinized organic soil indicated that corn is much more tolerant during germination than at the seedling stage. Some cultivars appeared more tolerant during germination than others. For example, seven days after planting, germination of Pioneer 3369A, Funk G4141, and Northrup King PX32 was reduced significantly at soil water