the soil salinity by a desired percentage (developed by U.S. Salinity Laboratory personnel), might be used to estimate the amount of water needed for seasonal salinity control where saline high water tables are present. For such areas, leaching would occur during the preplant irrigation. UC researchers have shown that, where preplant irrigations occurred, the spring soil salinity was the same for each year over a period of several years. Where no preplant leaching occurred, salinity continued to increase over the time interval.

Since successful leaching requires good drainage, some method of drainage water disposal may be needed in the Valley. Evaporation ponds, either on-farm or regional, are now the only short-term disposal method. A UC study is being conducted to determine the appropriate compromise between the size of an evaporation pond and the size of a tailwater recovery pond when upgrading a furrow system.

Conclusion

Water table levels are generally highest in winter and spring, because of preirrigations and rainfall, and lowest in late fall. Improved irrigation water management during the preirrigation and the first seasonal irrigation, such as upgrading existing furrow systems or changing to surge irrigation, thus may substantially reduce subsurface drainage. For existing furrow irrigation systems operated as well as possible, a 50 percent reduction in drainage may occur if the length of run and set time are reduced, as indicated by an ongoing UC study. Further reductions may be achieved by converting to surge irrigation. In drainage problem areas, still more reductions might occur with improved irrigation scheduling, water table management, or irrigation with drainage water.

In some areas, however, drainage reduction requirements established by regulatory agencies eventually may require irrigation systems with high uniformities, such as drip/trickle or low-energy precise-application systems. The uniformity of these systems is independent of soil and climatic factors but depends on hydraulic design and system maintenance to ensure precise application of water.

Controversy exists over the upslope contribution to the drainage problem. Estimates of upslope irrigation efficiencies show that the potential contribution may be substantial. Reducing this source of drainage water may be necessary for long-term drainage reduction.

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Saline drainage water reuse in a cotton rotation system

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Safflower, a more salt-sensitive crop than cotton, showed significantly lower yields as levels of salinity in the irrigation water increased. The field above, grown in rotation with cotton, received drainage water of 4,500 mg/L salinity; field below was irrigated with saline water of 9,000 mg/L.

Since reuse of subsurface, saline drainage water for irrigation is one means of decreasing the volume that must be disposed of, we have been studying its effects on crops. The objective of the research reported here was to evaluate the effect of irrigation with drainage waters of varying salinity levels on the growth and yield of crops grown in a typical cropping rotation in the San Joaquin Valley.

Field study

The research site is a 26-acre field on the El Rico Ranch of J. G. Boswell Company near Corcoran, California, in the Tulare Lake Basin. The soil is Tulare clay. The main, 20-acre site was divided into 24 plots.

The experimental treatments consisted of irrigating with water of six salinity levels, each replicated four times. The levels used in 1984 and 1985 were approximately 400, 1,500, 3,000, 4,500, 6,000, and 9,000 milligrams per liter (mg/L) of total dissolved solids. All plots received a preplant irrigation with the water of lowest salinity (canal water).

Water analyses

Analyses were done on the irrigation water applied to the plots (table 1). Relatively high-quality canal water obtained from local surface water sources was available for irrigation. This water was mixed with drainage water obtained from a Tulare Lake Drainage District drain.

Since the mixture contained a greater proportion of drainage water, the concentrations of nitrate, chloride, sulfate, and sodium ions increased substantially. Calcium and magnesium concentrations increased but did not reach the same relatively high levels. All constituents increased except bicarbonate, carbonate, and potassium ions.

The increase in sodium, at constant potassium, changed the sodium/potassium ratio from 14 to 279. An increase of sodium relative to potassium is known to be often harmful to biological systems.

Plant response

Cotton has been grown for two years and safflower for one year on plots irrigated with water at the six salinity levels.

Saline drainage water had little effect on cotton yield in the first and second years of these trials.

Representative samples of cotton plants were harvested over the season from the treated plots. Plants from a 3-foot length of row were sampled three times from four treatments (400, 3,000, 4,500, and 9,000 mg/L total dissolved solids) 81, 110, and 145 days after planting during the 1984 growing season. In 1985, plants were harvested seven times from the same four treatments 61, 87, 110, 125, 130, 137, and 146 days after planting. Each treatment was sampled at three sites within a replication. Results are thus based on 12 samples (three sites times four replications) from 3 feet of row.

Shoot biomass development in 1984 showed no treatment effect. In 1985, the development of shoot biomass was somewhat delayed. Initially, the growth rate (root and shoot length and biomass accumulation) was adversely affected by the salt content of the irrigation water; the effect was directly proportional to the salinity level. About 90 days after planting, however, the salt-affected plants began to recover and subsequently achieved the same growth rate as those irrigated with nonsaline water. The resulting difference was that plants irrigated with saline water were delayed by about two to three weeks in their development.

Saline drainage water applied to cotton in both 1984 and 1985 had no significant effect on yield. In 1984, the yield of cotton increased slightly with increasing salinity. Possibly the response reflects the common observation that cotton yield is favored by some stress. Also, drainage waters supply essential nutrients (table 1) that, if limiting, might cause a response in cotton.

We monitored soil salinity throughout the season in relation to treatment level. The time-averaged salinity during the crop season at depths of 1 and 2 feet increased with application of saline irrigation water during both 1984 and 1985. Both the absolute level and the rate of increase were greater in 1985, and the soil salinity in the 4,500 mg/L treatment attained a level approximately equal to the threshold of salinity above which cotton yields have been shown to decline. The soil solution conductivity was 11.5 decisiemens per meter (dS/m) in the 9,000 mg/L treatment. This level corresponds to an expected decline of about 20 percent in cotton yield (see Report #W-630 of the Water Resources Center, University of California, Riverside). These findings suggest that yield would be depressed by 20 percent at the highest treatment levels for the 1985 crop; the actual yields, however, were not depressed (table 2). This discrepancy could be related to the obvious variation in the soil environment and the distribution of roots relative to soil salinity levels.

Following the 1986 safflower crop, cotton was planted on April 15, 1987, on plots that had been irrigated previously with saline drainage water of varying concentrations. In preparation for planting, all plots were preirrigated with 400 mg/L water, and cotton was planted into moisture. Plants were sampled on May 28, before the first irrigation with saline drainage water. Total biomass was determined and plant densities measured (table 3).

The increasing salinity of previously applied irrigation water reduced both plant biomass and density. The effect on plant density was not as great as on biomass, but density was reduced by as much as 70 percent in plots that had been irri-

TABLE 1. Chemical analysis of Boswell water sampled 3/16/84; samples taken at outlet before application to plots

Item	Analysis at treatment (mg/L total dissolved solids):					
	400	1,500	3,000	4,500	6,000	9,000
	mg/L					
Electrical conductivity (EC), dS/m	0.95	2.46	4.95	6.95	9.34	11.6
pH	8.7	8.8	8.8	9.0	8.5	8.3
Sodium (Na), meq/L	4.79	17.5	42.0	63.5	87.4	109.0
Calcium (Ca), meq/L	1.60	2.01	3.45	5.9	6.11	8.82
Magnesium (Mg), meq/L	2.30	4.02	10.9	14.8	14.1	16.3
Potassium (K), meq/L	0.35	0.34	0.30	0.26	0.38	0.39
Bicarbonate (HCO_3), meq/L	3.1	3.2	4.4	4.3	4.7	5.2
Carbonate (CO_3), meq/L	0.80	1.6	1.8	2.3	1.6	1.1
Carbonate (CO_3), meq/L	2.05	5.19	11.3	15.6	51.4	70.6
Sulfate (SO_4), meq/L	3.66	15.0	37.6	59.0	59.4	74.8
Nitrate (NO_3), meq/L	1.4	3.3	7.6	10.0	25.0	22.0
Boron (B), ppm	0.64	1.1	1.9	2.9	4.3	4.5

NOTE: Water analysis done by J. Biggar, Department of Land, Air, Water Resources, UC Davis, and reported in Water Resources Technical Completion Report, #W-630.

gated with 9,000 mg/L irrigation water in the two previous cotton cropping seasons. Reduction of plant density below a critical level reduces yield, and this critical level may have been reached in the high-salinity plots.

We have continued to measure biomass during the growing season and will evaluate lint yield. The preliminary data presented in table 3 suggest that, after two years of irrigation with saline drainage water, the effect on crop establishment and development, and the reduction of yield in the third year of cotton, could be significant.

Safflower was grown for the first time as a rotation crop during the 1985-86 winter season. The crop was planted on January 26, 1986. One preirrigation was applied near the seeding date. The levees between treatments that were used for cotton irrigation were removed, and an application of good-quality water (400 mg/L) was made across all treatments. No more water was applied for the rest of the growing season.

The initial measurements of safflower biomass (March 27 and April 25, 1986) showed a significant effect of previously applied saline drainage water on growth and development of the crop. The specific effect on plant growth can be estimated by calculating weight per plant. Growth was little affected by previous treatments of up to 3,000 mg/L drainage water; at higher salinity levels, growth was suppressed substantially. For example, the 6,000 mg/L treatment reduced dry matter accumulation to 13 percent of the control, and 9,000 mg/L reduced dry matter accumulation to 10 percent of the control.

Salinity had a smaller effect on plant densities. At the 6,000 and 9,000 mg/L treatment levels, the number of safflower plants per square yard was approximately 50 percent of that of the control, suggesting that accumulated soil salinity has a greater effect on plant growth than on germination and emergence.

Saline drainage waters affected total biomass, plant density, and flowering rates of safflower to varying degrees, the most significant effects occurring at 6,000 and 9,000 mg/L. There was a similar effect on yield, with a significant reduction occurring at the highest level of salinity, 9000 mg/L (table 4).

Analysis of safflower oil composition showed no effect of salinity treatments on the relative amounts of saturated and unsaturated fatty acids, and thus no change in oil quality. Salinity also did not alter the percentage of oil in the safflower seed.

Conclusions

Application of drainage water with increasing levels of salinity increased the soil salinity at all levels sampled to a depth of 3 feet. The surface salinity to soil depths of 18 inches was more variable in response to applications of saline drainage waters because of leaching effects of either rainwater or preirrigation with good-quality water. High-quality water had little leaching effect at the 3-foot depth.

Leaching of salts from the top 18 inches appeared to be adequate to establish a cotton crop during the second year. Although soil salinity levels had accumulated to levels potentially harmful to cotton yield at the end of the first irrigation season, the crop showed no yield reduction during the second year of cotton production.

Safflower, more salt-sensitive than cotton, had significant reductions in yield at the highest levels of salinity in applied drainage waters. The effect appeared to be both on stand establishment and on subsequent crop growth.

The 1986 safflower crop was established in plots irrigated for two seasons with saline drainage water. Soil solution salinity had attained a conductivity of 15 dS/m by August 1985 and was reduced to approximately 9 dS/m in the top 12 inches by the spring of 1986 in the 9,000 mg/L treatments. The safflower was seeded into those plots in January 26, 1986. The 1985 cotton crop was seeded into plots irrigated with saline drain water during the 1984 cropping season, and the soil solution had attained a conductivity of 6 dS/m. The higher salinity level (9 dS/m) in the safflower plots compared with salinity at the initiation of the 1985 cotton crop could partially explain the relatively poor stand establishment of the safflower crop.

Major effects on the structure of the soil have been observed in plots irrigated with water having the highest salinity concentrations (6,000 and 9,000 mg/L). Soil permeability was reduced as a result of the increasing salination. To ensure effective water infiltration and to meet crop water demands in the 1985 season, more frequent irrigations were required for the 6,000 and 9,000 mg/L plots. Although the volume of water applied at each irrigation was less, at the end of the season, the total volume of water applied for the season was the same on all plots.

The extent of leaching of surface soil by rainwater and preirrigation with good-quality canal water suggested that the imposition of safflower rotation could possibly provide a surface soil adequately leached of salt to permit establishment of a cotton crop in the next season. In contrast to this expectation, preliminary data on cotton planted in April 1987 showed major reductions in emergence in the 6,000 and 9,000 mg/L treatments. Further measurements taken through the 1987 season will provide information on growth and development of the crop and on the yield of cotton irrigated with saline drainage water for three cotton cropping seasons. At least one more year of growing cotton in these plots following the 1987 crop will be required to determine the effect of saline drain water on this cropping system. These experiments underline the absolute necessity of establishing long-term plots to evaluate the effects of salinity on crop productivity and on soil physical and chemical properties.

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TABLE 2. Cotton lint yield as affected by salinity levels of irrigation water

Salinity TDS (mg/L)	1984* Kg/ha	1984* Bales/acre†	1985 Kg/ha	1985 Bales/acre†
400	1,570 ± 34.7	2.81 ± .06	1,160 ± 16.2	2.08 ± .03
1,500	1,740 ± 71.2	3.10 ± .13	1,280 ± 13.1	2.28 ± .02
3,000	1,700 ± 63.5	3.03 ± .11	1,230 ± 32.7	2.20 ± .06
4,500	1,750 ± 42.5	3.12 ± .08	1,210 ± 28.3	2.16 ± .05
6,000	1,760 ± 50.9	3.14 ± .09	1,280 ± 34.6	2.28 ± .06
9,000	1,720 ± 28.4	3.07 ± .05	1,160 ± 30.5	2.07 ± .05

*Total of two harvests
† 500 lb/bale

TABLE 3. Biomass and density of cotton growing in plots previously irrigated with saline drain water; sampling date May 28, 1987

Treatment, TDS (mg/L)	Density (plants/ 3-ft. row)	Biomass (g/3-ft. row)
400	17.5 ± 0.2	39.7 ± 1.6
1,500	19.4 ± 0.4	33.9 ± 1.0
3,000	15.4 ± 0.3	14.8 ± 1.6
4,500	15.5 ± 0.4	15.6 ± 0.7
6,000	10.3 ± 0.2	4.1 ± 0.5
9,000	7.7 ± 0.3	3.1 ± 0.3

TABLE 4. Yield of seed from safflower grown in 1986 on plots previously irrigated with saline drain water in 1984 and 1985; harvest date, August 5, 1986

Treatment (mg/L)	Density (plants/ 3-ft. row)	Yield (lb/acre)
400	78.4 ± 3.3	2,625 ± 34.3
1,500	75.6 ± 2.7	2,783 ± 66.3
3,000	75.5 ± 3.8	2,427 ± 48.3
4,500	74.9 ± 2.7	2,559 ± 91.1
6,000	53.0 ± 4.0	2,247 ± 83.7
9,000	54.0 ± 4.6	1,604 ± 68.6