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# Reuse of Drainage Water for Irrigation: Results of Imperial Valley Study

## I. Hypothesis, Experimental Procedures, and Cropping Results

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## II. Soil Salinity and Water Balance

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# ABSTRACTS

## I. Hypothesis, Experimental Procedures, and Cropping Results

An irrigation/cropping management strategy has been developed to facilitate the use of brackish waters for irrigation, with the goal of expanding the available water supply and minimizing the off-site pollution potential of drainage disposal. A field experiment conducted in the Imperial Valley of California to test the strategy has produced four years of cropping results. After seedling establishment, when the crops were in a sufficiently mature, salt-tolerant growth stage, brackish drainage water (Alamo River) was substituted for the normal water (Colorado River) to irrigate wheat and sugarbeets (in a succes-

*Continued inside back cover*

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# Reuse of Drainage Water for Irrigation: Results of Imperial Valley Study[1]

## I. Hypothesis, Experimental Procedures, and Cropping Results

### INTRODUCTION

Irrigated agriculture is a major consumer of water resources and contributor to its salt loading in arid and semi-arid regions. The agricultural community has a responsibility to conserve water and protect its quality as well as to sustain a viable, permanent irrigated agriculture. Irrigated agriculture cannot be sustained without adequate leaching and drainage to prevent excessive soil salinization. But these are the processes that contribute to the salt loading of water resources (Rhoades 1986).

Several strategies may be identified to cope with the increases in salinity of our surface-water and groundwater systems that result from irrigation (van Schilfgaarde and Rhoades 1984):

(1) Irrigation can be eliminated. This approach might be appropriate in some instances but, in general, it is untenable.

(2) Drainage return can be intercepted and diverted for disposal. For example, saline drainage water can be discharged into the sea, disposed of by evaporation in a pond, or injected into some appropriate deep aquifer.

(3) The water lost to seepage and deep percolation can be reduced by improved irrigation management, lessening the amount that passes through the subsoil and substrata. Since this deep-percolating water often dissolves additional salt from the substrata or displaces groundwater of even higher salinity, reducing it would decrease the salt load discharged to surface or groundwater, as well as decreasing some unrecoverable loss of water. Adoption of the so-called "minimized leaching" concept of irrigation management should thus be of appreciable benefit for reducing salinity pollution, as has been pointed out in detail (Rhoades et al. 1974; Rhoades and Suarez 1977; Suarez and Rhoades 1977; van Schilfgaarde et al. 1974).

(4) Drainage return can be desalted and reused or it can be used as a water supply without desalting in an application for which such brackish waters are suitable. Interception and reuse of drainage waters for irrigation would reduce the amount of brackish water and salt load discharged into receiving waters; with proper procedures, it could even increase the agricultural water supply for crop production in some cases. Reusing drainage water for irrigation would also decrease the volume of water requiring ultimate disposal or treatment as well as the capacities of the drain-

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age conveyance and treatment systems needed to cope with it. Off-site pollution problems often encountered with such disposal would also be reduced (Rhoades 1977, 1984b; Rhoades et al. 1980).

While improvement of irrigation management offers considerable potential to reduce the pollution of water systems and to conserve water, some practical constraints limit the implementation of such practices. But, in irrigation, the ultimate goals are to maximize the consumptive use of the irrigation water supply and to minimize deep percolation and drainage return-flow to the extent that the drainage water no longer has value for irrigation. To achieve these goals, drainage water should be intercepted and used again when feasible. Evidence of the ability to use drainage water for irrigation is discussed in detail elsewhere (Rhoades, 1977, 1988a).

Frequently, of course, drainage waters are returned by diffuse flow, as well as by intentional direct discharge, to a water supply and automatically reused after such mixing, a practice that may have some advantages in certain situations (Davenport and Hagan, 1982; van Schilfgaarde and Rhoades, 1984). The resulting increased water salinity, however, often limits the crops that can be grown with it. In some cases, such mixing may even decrease the volume of water usable for transpiration and crop growth. Greater management flexibility and opportunity for crop production result where the brackish drainage waters can be intercepted, isolated, and kept from the main water supply. This topic is discussed in detail elsewhere (Rhoades, 1988b).

## STRATEGY

A practical crop/water management strategy that maximizes the usability of saline waters for irrigation has been reported by Rhoades (1984a, 1984b, 1984c, 1986). This strategy is based on the premise that farmers will not voluntarily irrigate with brackish water unless it can be used without significant losses in yield, without major restrictions in cropping flexibility, and without extensive changes in farming practices and economic benefit.

The drainage water reuse strategy presupposes access to two water supplies: an irrigation water of low salinity ("good water") and a saline water that can still be consumed through transpiration by salt-tolerant crops without excessive loss in yield (water of less than about 8 decisiemens per meter [dS/m] in electrical conductivity). The saline water would be substituted for good water to irrigate certain crops in the rotation when they are in a suitably salt-tolerant growth stage; the good water would be used at the other times. The timing and amount of saline water substituted would vary with the quality of the two waters, the cropping pattern, the climate, the irrigation system, and the like.

Soil salinity will be lower in the root zone, especially during the critical periods of germination and seedling establishment, when saline water is used only as part of the water supply and only after seedling establishment. Any excessive salt buildup that occurs in the root zone from irrigating the "tolerant" crops in the rotation with the saline water can be alleviated in a subsequent cropping period when a more sensitive crop is irrigated with low-salinity water. After a salt-tolerant crop is grown, appropriate irrigation and seedbed management should "reclaim" the soil sufficiently to grow more sensitive crops without yield reduction. The cycle can be repeated indefinitely. This successive use of low- and high-salinity waters should prevent the soil from becoming excessively saline while permitting, over the long period, substitution of saline water for the conventional water for a substantial fraction of the irrigation needs of the area.

## EXPERIMENTAL SITE

The four-year experiment to test the feasibility of the crop/water management strategy was conducted under commercial field conditions in California's Imperial Valley. We chose the Imperial Valley, because more than 1 million acre-feet of drainage water (of approximately 3,000 mg/L) have been flowing annually into the Salton Sea (Kaddah and Rhoades 1976). The resulting rise in the Sea's water level has caused inundation problems recently for surrounding agricultural and nonagricultural communities. Use of this drainage water for irrigation would increase the quantity of water available for agricultural production in the Valley, while reducing discharge to the Salton Sea.

## EXPERIMENTAL DESIGN, PROCEDURES, AND INITIAL SOIL PROPERTIES

The field test was designed to determine crop yields and changes in soil salinity when representative Imperial Valley drainage water (Alamo River; about 3000 mg/L total dissolved salts [TDS]; electrical conductivity [EC] about 4.0 dS/m) was substituted for some of the Colorado River water, which is conventionally used for irrigation in the Valley (TDS about 900 mg/L; EC about 1.2 dS/m). Representative analyses of the Colorado and Alamo Rivers are given in table 1 (see table section at end of part I). Two crop rotations were used—a "successive-crop" and a "block" rotation. Each crop was grown with three different amounts of Alamo River substituted for Colorado River water. The three treatments were replicated six-fold.

In the successive-crop rotation of wheat:sugarbeets:cantaloupes, the irrigation water-quality treatments for wheat and sugarbeets were (1) use of Colorado River water solely (the control treatment [C]) and (2) use of both Colorado River and Alamo River waters with a relatively lesser (Ca) and greater (cA) proportion of Alamo River water. The actual amounts and proportions used are discussed in part II. In these treatments, Colorado River was used for the preplant and early-season irrigations of wheat and sugarbeets; the remaining irrigations on these crops were made with Alamo River water. For cantaloupes, only Colorado River water was used for irrigation. This crop rotation was repeated a second time during this four-year experiment.

In the four-year block rotation of cotton:cotton:wheat:alfalfa, cotton was grown for two consecutive years, followed by wheat and then by alfalfa for nearly two years. The irrigation water-quality treatments used in this rotation for cotton were (1) use of Colorado River water solely (the control [C]), (2) use of both Colorado River and Alamo River waters with Alamo River water substituted for Colorado River water for irrigations after seedling establishment (cA), and (3) use of Alamo River water solely for irrigation (A). Only Colorado River water was used to irrigate wheat and alfalfa. Treatment A was included to demonstrate the advantage of the proposed water management strategy (treatment cA), in which stand is established before the saline water is used for irrigation.

The 40-acre[2] field was leveled with laser equipment into two level benches. The water, either Colorado River or Alamo River, was conveyed to the field in a concrete-lined irrigation lateral canal. The successive-rotation crops were grown in the 18 level-basin plots (3 treatments x 6 replications) of the rectangular field in the lower left foreground of figure 1; the block-rotation crops were grown in the 18 plots to the right. The irrigation water was delivered to each plot (fig. 2) by diversion from the concrete-lined irrigation lateral shown across the bottom of figure 1, through a diversion chamber and portable calibrated flume (fig. 3), an open earthen conveyance ditch (fig. 2 and 3) and an outlet. When Alamo River water was used, it was pumped from a sump adjacent to the river, and discharged into the irrigation lateral (fig. 4) and then to the field.

The irrigation system delivered a flow of up to 2 cubic feet per second ($ft^3/s$) to each plot. Each plot was about 0.75 acre with irrigation runs of approximately 850 feet in length. The distribution efficiencies were calculated as

$$Du = 1 - (i_f t_t)/(Zg + Zg \bullet h)$$

where $i_f$ is final infiltration rate, $t_t$ is time for irrigation stream to advance to end of basin, $Zg$ is gross depth of water applied, and $h$ is advance exponent. Individual irrigations were evaluated to assess: (1) $t_t$ and $h$ from the record of the advancing water, (2) $Zg$ by measuring the volume of water applied and dividing by the basin area, and (3) $i_f$ by measuring the rate of fall of the water surface on the basin during the latter stages of the irrigation. The distribution-efficiency values ranged mostly between 90 and 98 percent (table 2). These distribution uniformities do not account for variability in infiltration rate within various sections of the plots. The field was underlain at a depth of 5 feet with tile drains spaced 150 feet apart (fig. 5).

The cooperating grower carried out all of the farming operations, including planting, fertilizing, cultivating, applying pesticides and herbicides, and harvesting, using conventional equipment and procedures. All treatments received identical management, including amounts and timing of irrigations. The timing and amounts of all early-season irrigations and some of the others were based on the advice of the farm manager. Established cotton and sugarbeet crops were irrigated when neutron probe readings showed 4 inches of soil moisture depletion within the root zone (4 feet); thus, about 4 inches of water were applied in individual irrigations.

Yields of each crop and relevant qualities when appropriate were determined. The parameters of yield and quality were variable, depending on the commercial purpose for which the crop was grown. The yields obtained by the commercial harvesting operations were generally used as the primary index of yield, although small areas were sometimes sampled by hand for backup purposes and for evaluating crop quality.

Compositions of the Colorado River and Alamo River waters were determined from samples collected at each irrigation.

The soil of the experimental area is mapped Imperial-Glenbar complex (Fine, montmorillonitic [calcareous], Hyperthermic Vertic Torrifluvents; Fine-silty, Mixed [calcareous], Hyperthermic Typic Torrifluvents). The texture is clay. The permeability of this soil is moderately slow (~0.10 to 0.15 inch per hour).

[2]Measurements are in English units, since irrigation, weighing, and farming equipment were scaled in these units. S.I. equivalents of selected English units are given on the inside back cover.

Fig. 1. Experimental field, looking west. The successive-crop rotation area is at left and block rotation area at right in the foreground. Alamo River is across the top and irrigation lateral across the bottom.

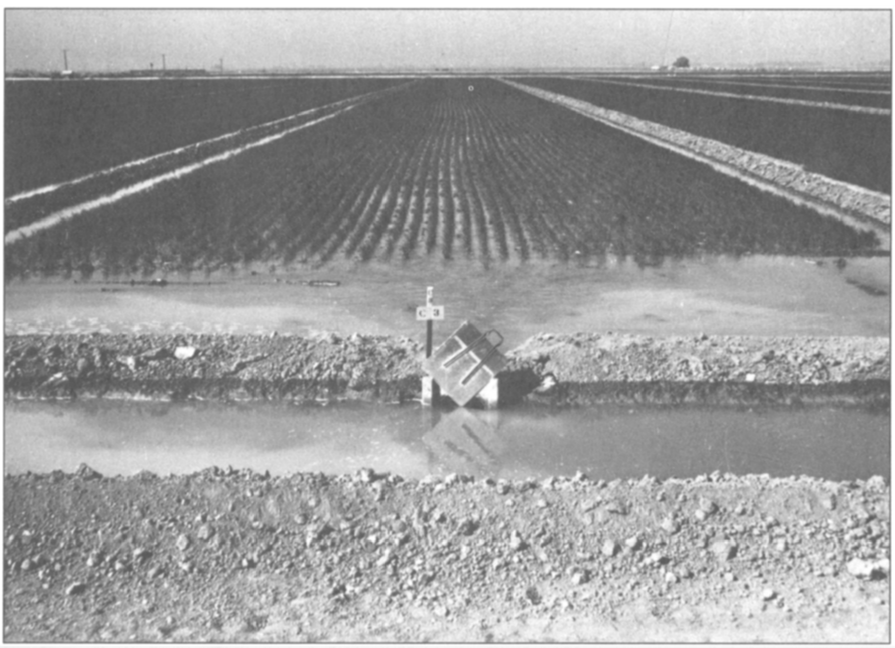

Fig. 2. Outlet into a replicate basin.

Fig. 3. Portable calibrated flume and two-way diversion chamber.

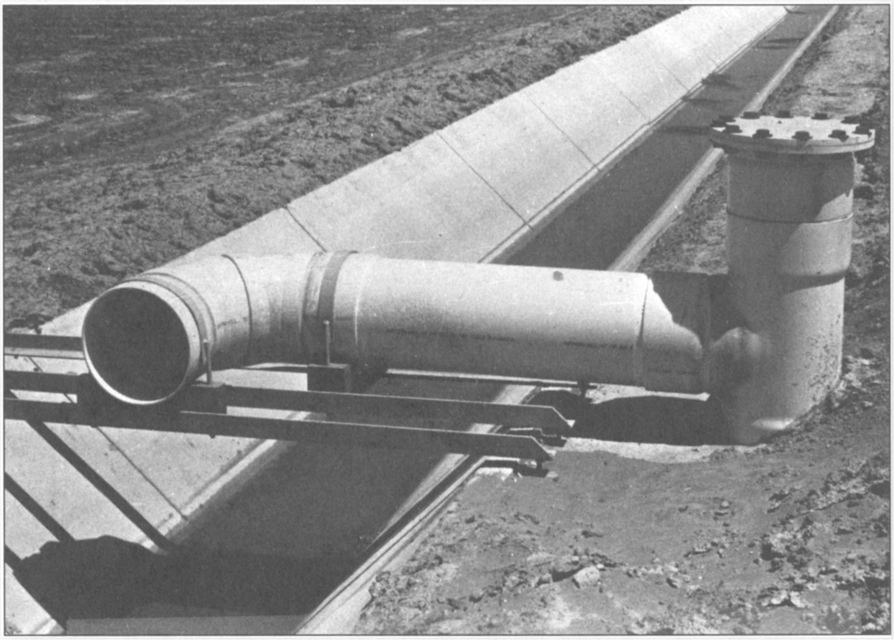

Fig. 4. Outlet of pipe from Alamo River to irrigation lateral.

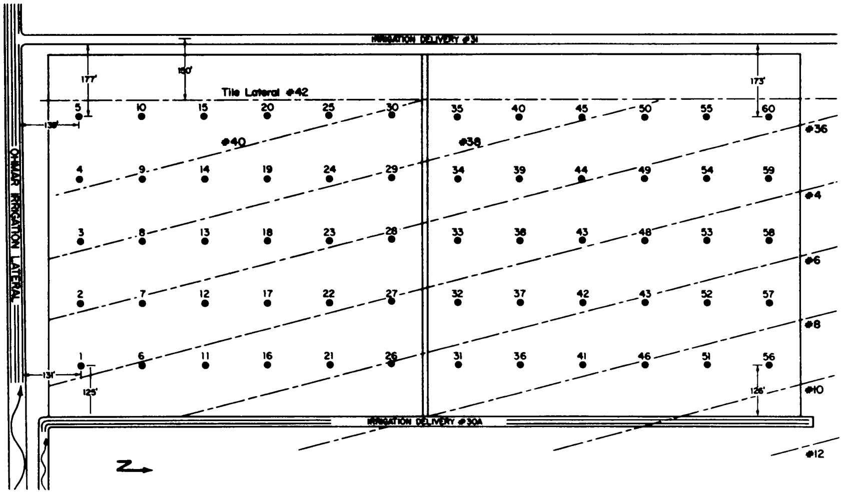


Fig. 5. Layout of tile drain system and sites (1 to 60) where initial soil samples were collected.

We characterized the initial soil conditions by analyzing 240 samples of the soil collected at 60 locations (the loci of a 150- by 150-foot grid system) in the field (fig. 5). The samples were collected on December 15 and 16, 1981, with a 2-inch-diameter auger, from four soil depth-intervals (3-9, 15-21, 27-33, and 39-45 inches). These samples were analyzed for electrical conductivity (EC), sodium adsorption ratio (SAR), and boron concentration (B) in saturated soil-paste extracts. The samples were also analyzed for saturation percentage (SP), gravimetric and volumetric soil water content at field capacity ($P_w$ and $\theta_v$), bulk density, and particle size distribution (% sand, silt, and clay).

Average properties of the soil samples are given in table 3 for the various soil depths. The mean contents of clay, silt, and sand in the sampled profile were 47, 37, and 16 percent, respectively. The average bulk density was 1.45 g/cm$^3$. The average "field capacity" water content of the sampled profile was 29.8 percent by weight and 43.3 percent by volume (5.2 inches per foot). The soil was initially low to medium in salt status.

## RESULTS

### Crop Yields

#### Successive Crop Rotation

No significant differences in wheat and sugarbeet yields occurred in either cycle of the successive-crop rotation as a result of substituting drainage water (even in the greater amount of 65 to 75 percent) for Colorado River water to irrigate these crops after seedling establishment (table 4). The mean yields of cantaloupe seed among treatments were not statistically significantly different. The yields of fresh-market melons (numbers of cartons of cantaloupes obtained by commercial-harvest operations) in 1985 also were not significantly different. Hence, no yield loss was observed from growing cantaloupes using Colorado River water for irrigation (either for seed or fresh melons) on the land previously salinized from the irrigation of wheat and sugarbeets using drainage water.

The commercial harvesting operation employed for the fresh-melon market involved the subjective elimination by the hand-harvesting crew of melons of inferior quality, based on visual appearance. These yields thus represent those of commercially suitable quality. The year 1985 was not favorable for fresh-market melons in the Imperial Valley, since black fungus and yellow virus damage were prevalent. The crop would have been picked once more had not an intervening rain prevented it.

The yields obtained by hand-harvesting 30 foot-long sections of row, as expressed in terms of total weight of melons, were lower in the plots that had been previously irrigated with Alamo River (see table 7). But, as will be discussed later, melon quality was better in these plots. This quality difference apparently explains the lack of any measured loss of commercial yield of fresh-market melons in these plots.

### Block Rotation

In the block rotation, commercial harvesting operations revealed no loss in lint yield in the first cotton crop (1982) from use of Alamo River water for irrigation, even when it was used during the preplant and seedling establishment periods. This 1982 cotton crop was grown in sloping beds to facilitate seedling establishment.

There was no significant loss in lint yield in the second cotton crop (1983) from use of Alamo River water for the irrigations that followed seedling establishment with Colorado River (cA). There was a substantial loss of lint yield, however, where only Alamo River water was used for irrigation (A). This loss resulted primarily from a decrease in the stand caused by excessively high salinity in the seedbed during the seedling establishment period (as discussed in part II).

The problem of poor stand apparently was accentuated in 1983, because sloping beds were not used during the seedling establishment period, as they were in 1982. Furthermore, conditions in 1983 were not favorable for seedling emergence because rainfall caused surface crusting problems. The commercial fields in the surrounding area were replanted because of this problem, but the experimental area was not. The growing season was also longer in 1982 than in 1983. These circumstances partly explain the relatively low lint yields obtained in 1983 compared with those in 1982.

No statistically significant loss in wheat grain or alfalfa hay yield occurred in the block rotation on plots previously irrigated with Alamo River water. Grain yields were high and essentially the same as those obtained in the successive crop rotation plots. Likewise, hay yields were above average for this area, even though the alfalfa was slightly under-irrigated by furrow irrigation (discussed in part II).

## Qualities of Crops

### Successive Crop Rotation

The grain irrigated with Alamo River water after seedling establishment was superior in quality (for purposes of bread baking) to that in the control treatment in 1982 (table 6). The flour of the cA wheat grain was significantly higher in protein and produced a loaf of significantly greater volume in 1982. The beneficial relation between loaf volume and protein percentage for this wheat flour (1982) is shown in figure 6. No significant differences in protein content and loaf volume were found between treatments in 1983.

Various measurements of the quality of fresh-market cantaloupes in the hand-harvested sample set of 1985 are given in table 7. The number of fruit decreased with increasing amounts of Alamo River water, and fruit size was smaller in the cA treatment. On the other hand, melons collected from the Alamo River treatment plots were of better quality in terms of "netting" and flesh color. Melons of the C treatment were rated poorer in quality than those of the Ca and cA treatments. This finding probably explains why the commercial yield was higher in the cA plots, since the harvesting crew discarded all fruit of low quality. The sugar contents were not significantly different among treatments.

## Block Rotation

**Cotton crops, 1982, 1983.** The quality analyses of the commercially picked cotton lint were done in different laboratories and by somewhat different methods in 1982 than in 1983 (tables 8 and 9). Within each year, the lint was of high and similar quality irrespective of treatment.

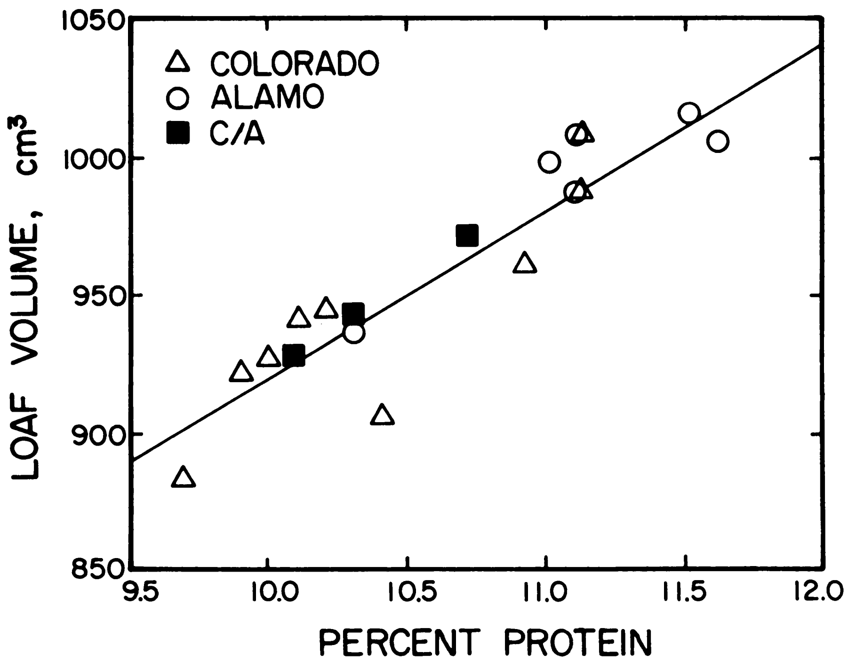


Fig. 6. Relation between loaf volume and protein percentage in flour from wheat irrigated with Colorado and Alamo River water.

**Wheat crop, 1984.** Contrary to the results obtained in the successive crop rotation, no significant differences in bread-baking quality between treatments were observed in the block rotation (table 10). The reason is probably that the salinity differences between treatments earlier in these fields (after cotton) were eliminated within the crop's major root zone upon return to irrigation with Colorado River water. These salinity data are discussed in part II.

**Alfalfa crop, 1985.** The hay was significantly higher in protein content and in total digestible nutrients in the plots that had been irrigated with Alamo River water (table 11). Apparently, the higher salinity in the deeper soil depths within these plots exerted some "stress influence" that improved hay quality. These salinity data are discussed in part II.

## SUMMARY AND CONCLUSIONS

A strategy for irrigating crops with saline drainage water was tested under actual commercial field conditions in the Imperial Valley of California. Drainage water (Alamo River) was substituted for the "normal water" (Colorado River) to irrigate sugarbeets and wheat (in a successive crop rotation) and cotton (in a block rotation) following seedling establishment—a time when the crops were sufficiently mature and more tolerant of higher levels of salinity. A good stand was obtained under the lower salinity conditions achieved by pre-irrigating with Colorado River water instead of Alamo River water.

Irrigating the other crops in the rotations only with Colorado River water leached out excessive salt accumulations from the previous use of the saline drainage water. Soil salinity was thus kept within acceptable limits, so that crop production and quality were sustained when salt-sensitive crops (cantaloupes and alfalfa) were grown on the same land. The high crop yields and qualities obtained in this field test support the validity of the proposed management strategy. The resulting conditions of soil salinity are discussed in part II.

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TABLE 1. COMPOSITIONS OF COLORADO AND ALAMO RIVER WATERS

| Water/statistics | EC | SAR* | B | Ca | Mg | Na | K | Alk | $SO_4$ | Cl | $NO_3$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | dS/m | $(mmol_c/L)^{1/2}$ | mg/L | ———— | ———— | ———— | $mmol_c/L$ | ———— | ———— | ———— | ———— |
| *Colorado River* | | | | | | | | | | | |
| Number of samples | 50 | 50 | 46 | 48 | 50 | 50 | 49 | 45 | 40 | 48 | 11 |
| Mean value | 1.25 | 3.2 | .31 | 4.1 | 2.6 | 5.7 | .11 | 2.6 | 6.6 | 3.1 | .05 |
| Standard deviation | .13 | .5 | .12 | 1.2 | .3 | 1.0 | .04 | .5 | .9 | .5 | .02 |
| Standard error of mean | .02 | .07 | .02 | .2 | .04 | .1 | .01 | .07 | .1 | .1 | .01 |
| *Alamo River* | | | | | | | | | | | |
| Number of samples | 34 | 33 | 32 | 31 | 34 | 34 | 33 | 34 | 20 | 31 | 16 |
| Mean value | 4.0 | 8.2 | .8 | 10.3 | 8.9 | 25.1 | .32 | 4.4 | 22.2 | 18.4 | .7 |
| Standard deviation | .3 | 1.5 | .3 | 2.1 | 1.2 | 4.4 | .05 | 1.3 | 4.0 | 2.1 | .6 |
| Standard error of mean | .06 | .3 | .06 | .4 | .2 | .7 | .01 | .2 | .9 | .4 | .2 |

*Sodium adsorption ratio = $Na/[(Ca + Mg)/2]^{1/2}$, where all solute concentrations are in mmol/L.

TABLE 2. DISTRIBUTION UNIFORMITIES OF IRRIGATION OF SELECTED LEVEL-BASIN PLOTS CROPPED TO WHEAT

| Basin | Flow rate to basin | Gross depth applied (Zg) | Final infiltration rate ($i_f$) | Distribution uniformity (DU) |
|---|---|---|---|---|
| | $ft^3/s$ | *inches* | *in./hr* | % |
| *April 28, 1982—4th irrigation* | | | | |
| Ca2 | 2.2 | 5.4 | 0.12 | 96 |
| cA3 | 2.2 | 4.9 | .10 | 97 |
| cA4 | 2.2 | 4.9 | .17 | 95 |
| *December 28, 1983—1st irrigation* | | | | |
| A2 | 1.8 | 5.8 | 0.55 | 84 |
| A5 | 1.8 | 5.1 | .36 | 90 |
| C2 | 1.6 | 6.1 | .29 | 90 |
| C5 | 1.6 | 5.4 | .27 | 91 |
| *March 7, 1984—3rd irrigation* | | | | |
| A2 | 1.8 | 4.8 | 0.07 | 97 |
| A5 | 2.0 | 5.0 | .04 | 98 |
| C2 | 1.8 | 4.4 | .06 | 98 |
| C5 | 2.0 | 5.0 | .11 | 96 |

NOTE: Distribution efficiencies were calculated as $DU = 1 - \frac{i_f t_t}{Zg(1+h)}$ where $i_f$ is final infiltrarate, $t_t$ is time for irrigation stream to advance to end of basin, Zg is gross depth of water applied, and h is advance exponent. Individual irrigations were evaluated to assess: (1) $t_t$ and h from the record of the advancing water, (2) Zg by measuring the volume of water applied and dividing by the basin area, and (3) $i_f$ by measuring the rate of fall of the water surface on the basin during the latter stages of the irrigation. (Measurements made by Dr. Al Dedrick).

TABLE 3. SELECTED SOIL PROPERTIES*

| Property | Depth (inches): 0-12 | 12-24 | 24-36 | 36-48 |
|---|---|---|---|---|
| Clay, % | 46.0 (0.9) | 51.0 (1.1) | 49.9 (2.1) | 40.5 (1.9) |
| Silt, % | 36.0 (0.8) | 34.0 (1.1) | 35.5 (1.4) | 43.4 (1.6) |
| Sand, % | 17.8 (0.8) | 15.1 (1.0) | 14.6 (1.1) | 15.8 (0.9) |
| Bulk density, $g/cm^3$ | 1.45 (.02) | 1.43 (.02) | 1.46 (.01) | 1.44 (.02) |
| Water content at "field capacity," % by weight | 28.1 (0.2) | 29.8 (0.3) | 30.6 (0.2) | 30.9 (0.2) |
| $pH_e$ | 7.60 (.04) | 7.40 (.05) | 7.30 (.05) | 7.20 (.04) |
| $EC_e$, dS/m | 2.9 (0.2) | 3.8 (0.2) | 5.3 (0.3) | 6.4 (0.4) |
| $SAR_e$, $(mmol_c/L)^{1/2}$ | 5.4 (0.1) | 5.9 (0.2) | 7.0 (0.4) | 8.6 (0.5) |
| $B_e$, mg/L | 0.9 (0.1) | 0.8 (0.1) | 0.7 (0.1) | 0.8 (0.1) |

*Values within parentheses are standard error of mean where the number of measurements were 50-60 for texture, water content and chemistry and 18 for bulk density.

TABLE 4. YIELDS OF CROPS IN SUCCESSIVE ROTATION*

| Treatment† | Crop/year: Wheat/ 1982‡ | Sugarbeets/ 1983§ | Cantaloupes/ 1983¶ | Wheat/ 1984‡ | Sugarbeets/ 1985§ | Cantaloupes/ 1985# |
|---|---|---|---|---|---|---|
| C | 3.60 (0.06) | 4.3 (0.1) | 392 (12) | 3.51 (0.09) | 4.1 (0.1) | 115 (5) |
| Ca | 3.60 (0.08) | 4.3 (0.2) | 384 (10) | 3.46 (0.10) | 4.1 (0.1) | 142 (8) |
| cA | 3.71 (0.06) | 4.1 (0.1) | 355 (14) | 3.55 (0.09) | 3.9 (0.1) | 139 (12) |

*Values within parentheses are standard error of mean; six replicates.

†C = Only Colorado River water used for irrigation; Alamo River water used in relatively smaller (Ca) and larger (cA) amounts, after seedling establishment with Colorado River water for wheat and sugarbeets. Cantaloupes only irrigated with Colorado River water.

‡Tons of grain per acre.

§Tons of sugar per acre.

¶Pounds of seed per acre.

#Commercial yield in number of cartons per plot; plot size = 750 × 38 feet = 0.6543 acres.

TABLE 5. YIELDS OF CROPS IN BLOCK ROTATION*

| Treatment† | Crop/year: Cotton/1982‡ | Cotton/1983‡ | Wheat/1984§ | Alfalfa/1985¶ |
|---|---|---|---|---|
| C | 2.62 (.07) | 2.06 (.10) | 3.43 (.06) | 7.8 (0.4) |
| cA | 2.65 (.06) | 2.00 (.09) | 3.43 (.06) | 7.0 (0.5) |
| A | 2.76 (.04) | 1.32 (.05) | 3.41 (.05) | 7.4 (0.3) |

*Values within parentheses are standard error of mean; six replicates.

†C = Only Colorado River water used for irrigation; A = Alamo River water used solely for irrigation; cA = Alamo River water used for irrigation after seedling establishment with Colorado River water for cotton. Wheat and alfalfa irrigated only with Colorado River water.

‡Commercial yield of lint, bales (480 pounds) per acre.

§Tons of grain per acre.

¶Tons of dry hay per acre.

TABLE 6. AVERAGE BREAD-BAKING QUALITIES OF WHEAT GRAIN IN SUCCESSIVE CROP ROTATION BY TREATMENT AND YEAR*

| Treatment† | Flour yield | | Flour protein | | Loaf volume | | Milling score | | Test weight | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1982 | 1984 | 1982 | 1984 | 1982 | 1984 | 1982 | 1984 | 1982 | 1984 |
| | % | % | % | % | *cm*$^3$ | *cm*$^3$ | % | % | *lb/bu* | *lb/bu* |
| C | 71.3 (0.5) | 68.7 (0.7) | 10.3 (0.2) | 10.6 (0.2) | 938 (11) | 843 (28) | 82.3 (1.1) | 78.1 (1.2) | 64.9 (0.1) | 63.7 (0.1) |
| Ca | 71.4 (0.4) | 68.0 (0.7) | 10.5 (0.2) | 10.8 (0.2) | 950 (17) | 824 (25) | 83.3 (0.6) | 77.2 (1.0) | 64.9 (0.1) | 64.1 (0.4) |
| cA | 71.4 (0.4) | 68.4 (0.8) | 11.1 (0.2) | 11.1 (0.1) | 993 (12) | 877 (27) | 83.4 (0.7) | 77.7 (1.1) | 65.0 (0.2) | 63.8 (0.1) |

*Values within parentheses are standard error of mean; six replicates.

†Only Colorado River water used for irrigation; Alamo River water used for irrigation in relatively lesser (Ca) and greater (cA) amounts after seedling establishment with Colorado River water.

TABLE 7. QUALITIES OF CANTALOUPES IN HAND-HARVESTED SAMPLE SET, 1985 CROP*

| Treatment† | No. of melons | Mean wt. of melons | Total weight | Net quality‡ | Color quality‡ | Sugar content |
|---|---|---|---|---|---|---|
| | | *kg* | *kg* | | | % |
| C | 44 (2) | 1.03 (.01) | 46.6 (2.0) | 1.85 (.06) | 1.70 (.12) | 9.6 (0.2) |
| Ca | 41 (3) | 1.02 (.03) | 41.1 (3.1) | 2.13 (.06) | 2.07 (.08) | 9.9 (0.1) |
| cA | 37 (3) | 0.93 (.02) | 34.6 (3.1) | 2.28 (.05) | 2.04 (.10) | 9.3 (0.1) |

*Values within parentheses are standard error of mean; six replicates.

†Only Colorado River water used for irrigation of this crop; Alamo River water was used to irrigate the wheat and sugarbeet crops grown previously in these plots in lesser (Ca) and greater amounts (cA).

‡Quality values: 1 = poor; 2 = good; 3 = excellent.

TABLE 8. QUALITIES OF LINT OF COMMERCIALLY HARVESTED COTTON CROP*

| | Quality measurements‡ | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Treat-ment†** | **Micron-aire** | **Length** | **Uniformity ratio** | **Strength** | **$T_1$** | **$E_1$** | **RD** | **+B** |
| C | 4.42(.04) | 1.09(.00) | 80.2(0.3) | 23.7(0.3) | 23.9(0.2) | 5.0(.06) | 79.2(0.3) | 7.1(0.1) |
| Ca | 4.35(.08) | 1.09(.01) | 80.8(0.5) | 23.3(0.2) | 24.2(0.5) | 5.3(0.1) | 79.5(0.4) | 7.4(0.1) |
| A | 4.37(.03) | 1.09(.01) | 80.7(0.3) | 23.8(0.3) | 24.7(0.3) | 5.0(0.0) | 79.3(0.3) | 7.3(0.1) |

NOTE: Quality analysis performed by H.V.I. at the Textile Research Center, Texas Tech. University, Lubbock, Texas; samples had been in storage for two years before analysis.

*Values within parentheses are standard error of mean; six replicates.

†C = only Colorado River water used for irrigation; A = Alamo River water used solely for irrigation; cA = Alamo River water used for irrigation after seedling establishment with Colorado River water.

‡Micronaire = an expression of fiber fineness used in cotton classification; length, expressed in hundredths of an inch; uniformity ratio, a measure of uniformity, values within range 80-82 are average; strength, expressed in terms of grains per tex; $T_1$ = tensile strength of fiber bundle; $E_1$ = elongation, a measure of elasticity; RD = an expression of grayness of color; and +B an expression of yellowness of color.

TABLE 9. QUALITIES OF LINT OF COMMERCIALLY HARVESTED 1983 COTTON CROP*

| | Quality measurements‡ | | | | | |
|---|---|---|---|---|---|---|
| **Treatment†** | **2.5% SL** | **50% SL** | **U.I.** | **$T_1$** | **$E_1$** | **Micronaire** |
| C | 1.12 (.01) | .50 (.00) | 44.7 (0.2) | 22.2 (0.5) | 8.4 (0.1) | 4.6 (.05) |
| cA | 1.11 (.01) | .50 (.00) | 45.2 (0.3) | 22.5 (0.4) | 8.2 (0.1) | 4.5 (.07) |
| A | 1.12 (.01) | .49 (.00) | 44.0 (0.4) | 22.6 (0.2) | 8.5 (0.1) | 4.5 (.07) |

NOTE: Quality analysis performed by Gus Hyer of the Cotton Research Laboratory, Shafter, California.

*Values within parentheses are standard error of mean; six replicates.

†C = only Colorado River water used for irrigating; A = Alamo River water used solely for irrigation; cA = Alamo River water used for irrigations after seedling establishment with Colorado River water.

‡2.5% SL = length in inches spanned by 2.5% of the fibers; 50% SL = length in inches spanned by 50% of the fibers; U.I. = ratio of the 50% SL to the 2.5% expressed as percentage, a measure of uniformity; $T_1$ = tensile strength of a fiber bundle expressed as grams per Tex; $E_1$ = elongation, a measure of elasticity; micronaire = fineness of a sample expressed in standard micronaire units.

TABLE 10. AVERAGE BREAD-BAKING QUALITIES OF 1984 WHEAT GRAIN IN BLOCK ROTATION*

| Treatment† | Flour yield | Flour protein | Loaf volume | Milling score | Test weight |
|---|---|---|---|---|---|
| | % | % | *cm³* | % | *lb/bu* |
| C | 69.7 (0.4) | 11.1 (0.1) | 827 (9) | 81.3 (0.6) | 63.9 (0.1) |
| cA | 68.8 (0.6) | 10.9 (0.1) | 761 (11) | 79.2 (0.8) | 64.1 (0.1) |
| A | 69.0 (0.3) | 10.8 (0.1) | 772 (17) | 79.6 (0.5) | 63.8 (0.1) |

*Values within parentheses are standard error of mean; six replicates.

†Only Colorado River water was used for the irrigation of this crop; Alamo River water was used to irrigate the two preceding crops solely (A) or after seedling establishment with Colorado River water (cA).

TABLE 11. AVERAGE QUALITIES OF ALFALFA HAY IN THE BLOCK ROTATION, SAMPLED 8/7/85*

| Treat-ment† | Quality measurements‡ | | | | | | |
|---|---|---|---|---|---|---|---|
| | Moisture§ | Crude protein | Digestible protein | Modified crude fiber | Crude fiber | Total digestible nutrients | Estimated net energy |
| | % | % | % | % | % | % | *Kcal/lb* |
| C | 73.8 (0.7) | 15.9 (0.5) | 16.8 (0.8) | 25.6 (1.5) | 23.2 (1.4) | 59.1 (1.3) | 487 (15) |
| cA | 73.4 (0.4) | 15.5 (0.8) | 16.2 (0.9) | 26.5 (1.5) | 24.5 (1.3) | 58.2 (1.4) | 476 (16) |
| A | 73.3 (0.6) | 17.7 (0.6) | 18.9 (0.4) | 21.8 (0.8) | 20.0 (0.8) | 62.4 (0.6) | 524 (6) |

NOTE: Analyzed by Agricultural Technical Service, Inc., Brawley, California.

*Values within parentheses are standard error of mean; six replicates.

†Only Colorado River water was used for the irrigation of this crop; Alamo River water was used to irrigate the two cotton crops solely (A) or after seedling establishment with Colorado River water (cA).

‡Protein,fiber, total digestible nutrients, and energy: 100% dry basis.

§As received in lab.

*Continued from inside front cover*

**sive crop rotation of wheat:sugarbeets:cantaloupes) and cotton (in a block rotation of cotton:cotton:wheat:alfalfa). A good stand was obtained under relatively low conditions of salinity by using Colorado River water for the preplant and early-season irrigations.**

**The salt-sensitive crops in the rotations (cantaloupes and alfalfa) were irrigated with Colorado River water only. This procedure kept soil salinity within acceptable limits over time so that production and quality were sustained when the sensitive crops were grown on the same land.**

**The high crop yields and qualities obtained in this field test support the validity of the recommended strategy.**

## II. Soil Salinity and Water Balance

**This paper presents data on water use and soil salinity status obtained in the field experiment—the remaining information needed to complete the "strategy verification" process. These data, together with those presented in part I, support the use of saline drainage waters for irrigation for the following reasons: (1) Soil salinity and boron were kept within acceptable limits for seedling establishment and subsequent growth of the individual crops grown in the rotations. (2) No significant loss of yield or crop quality occurred in any of the five crops grown with substitution of the saline Alamo River water for Colorado River water for up to 25 to 50 percent of the total irrigation requirements of the two representative rotations. (3) No problems of soil degradation were observed, even though accumulative leaching was minimal (less than 15 percent), with the clay soil.**

### S.I. EQUIVALENTS OF SELECTED ENGLISH UNITS

| English | S.I. |
|---|---|
| 1 acre | 0.405 hectare (ha) |
| 1 foot (ft) | 0.304 meter (m) |
| 1 inch (in) | 2.54 centimeters (cm) |
| 1 cubic foot ($ft^3$) | 28.3 liters (L) or 0.0283 cubic meters ($m^3$) |
| 1 acre-foot | 12.33 ha-cm |
| 1 ton (2000 lb) | 0.907 tonne (t) |
| 1 ton/acre | 2.24 t/ha |
| 1 pound (lb) | 0.454 kilogram (kg) |
| 1 lb/acre | 1.12 kg/ha |
| 1 pound/bushel (lb/bu) | 12.87 $kg/m^3$ |



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