

PROJECT TITLE: CONTINUATION IN THE LONG-TERM CYCLIC USE OF SALINE DRAINAGE WATER IN A ROTATION OF COTTON AND PROCESSING TOMATO

PROJECT NUMBER: 90-20

DURATION OF FUNDING: July 1990 - June 1993

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Drain water
Reuse -
Reached shallow water table
uptake by plants

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ABSTRACT:

Use of saline drainage water for irrigation is one of only a few on-farm water management options available of growers on the west side of the San Joaquin valley as a means of reducing their effluent volumes. The cyclic use of saline drainage water and good quality water was tested as a method of conserving California aqueduct water, reducing drainage volume, and improving

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ABSTRACT:

Use of saline drainage water for irrigation is one of only a few on-farm water management options available of growers on the west side of the San Joaquin valley as a means of reducing their effluent volumes. The cyclic use of saline drainage water and good quality water was tested as a method of conserving California aqueduct water, reducing drainage volume, and improving

tomato quality without affecting crop yield. A long-term study was initiated in 1986 at the westside field station to test the feasibility of two, cyclic drainage-water use strategies in a three year rotation of tomato-cotton-cotton. In both strategies, saline drainage water was used as the sole source of irrigation water for the tomato crop after it reached first bloom. This was done to obtain advantage of salinity's enhancement of fruit quality. In one strategy, non-saline water was used at all other times within the three-year rotation. In the other strategy, saline drainage water was also used to irrigate the cotton crop following the tomato crop, after pre- and early irrigations with non-saline water. A control treatment was also employed where non-saline water was used at all times. To sort out yearly variation, each of these three irrigation treatments (two reuse treatments and the non-saline control treatment) was initiated in 1986 at each of the three points in the cropping rotation. Crop yields, crop quality, selected physiological parameters, water infiltration, and soil chemical parameters were measured.

After the first four years of investigation, saline drainage water ($EC = 7.3$ to 7.7 dS/m and 5 mg/L B) regardless of whether it was applied one, two, or three out of four years, did not reduce the yields of either cotton lint or tomato fruit. After the fifth year (1990 season), the yields of processing tomato fruit (cv FM 785) from plots that received drainage water were only 60% of those from the non-salinized control plots. In 1991, yields of red tomatoes from plots treated with salinity one out-of-three years, and two out-of-three years were 91 and 82% of those irrigated only with non-saline water yet this difference was only significant for the later treatment. In 1992, respective yields from plots treated with drainage water were 94 and 78% those from non-saline controls, but again only the later treatment was significantly different. On the other hand irrigation with saline drainage water improved fruit quality by increasing soluble solids ($^{\circ}$ Brix) relative to those in non-saline control plots. This effect was significant (5% level) in 1987, 1989, and 1990 in those plots that received drainage water one out-of-three and in 1989, 1990, 1991, and 1992 in those plots that received drainage water two out-of-three years. Lint yield of cotton was not reduced by saline drainage water for the first 5 years. However, there was more vegetative cotton growth in plots that received drainage water in 1990 and to a lesser extent those that were salinized in previous years, than cotton grown in control plots. This was presumably due to high concentrations of NO_3 in the drainage water. In 1991, the sixth year, irrigation with saline drainage water applied two out-of-three years reduced lint yields up to 15% in both SJ-2 and GC-510 cultivars but this reduction was only significant for GC-510.

Irrigation with non-saline water displaced a large amount of the salts, boron, and selenate that accumulated during one or two years of irrigation with drainage water in the upper 60 cm of soil. Selenate concentrations were substantially lowered by irrigation with non-saline water even at depths below 60 cm. However, at depths below 60 cm, concentrations of salts and boron have gradually increased over the years in plots receiving drainage water. These results indicate that the

gradual buildup of salt and boron at lower depths in the crop root zone is a major factor that could limit the feasibility of this cyclic strategy unless irrigations are carefully managed to insure sufficient leaching of these constituents during pre- and early irrigations. If a favorable balance of salt and boron can be effectively maintained within the root zone, then irrigation with saline drainage water (EC = 7.3 to 7.7 dS/m and 5 mg/L B) one out-of-three years, utilizing the proposed strategy and rotation, is feasible.

Keywords: boron, fruit-quality, reuse, salinity, selenium transient.

PROJECT OBJECTIVES ADDRESSED:

1. To determine the feasibility of a cyclic drainage water reuse practice for processing tomato and cotton production on the west side of the San Joaquin Valley, and identify physical, chemical and biological limitations to the strategy.
2. To determine the long-term effects of one, or two out-of-three seasons of saline drainage water application on crop yield, crop quality, and soil quality.
3. To assess the potential long-term bio-hazard from selenium accumulation in soils and plant material and the extent to which this could be alleviated by varying the proportion of saline/non-saline water applied during the rotation cycle.

RESEARCH PLAN AND PROCEDURES:

A six-year study was initiated in 1986 at the University of California, Westside Field Station (WSFS) to address the objectives above. Many researchers have explored the possibility of using saline and/or agricultural drainage water for irrigation (Meiri, et al., 1986; Pasternak et al., 1986; Rains et al., 1987; and Rhoades, 1984; 1987). We designed a "cyclic" irrigation strategy similar to that described by Rhoades (1987). That is, rather than blend water of different qualities before irrigation, treatments were designed that would cycle between fresh California Aqueduct water and saline drainage water on a year-to-year basis. A cyclic pattern of reuse has several advantages over blending water of different qualities during each irrigation: i.e., more salt sensitive (and generally higher value) crops can be incorporated into the rotations, no blending facility is needed and drainage water of higher salinity may be used (Grattan and Rhoades, 1990). The presence of potentially toxic elements in this water, however, raises concerns about the movement of these elements into food chains.

Three irrigation water treatments were superimposed onto a three-year crop rotation typical of this region, (one year of processing tomatoes followed by two years of cotton). The three water treatments were: (1) irrigation with fresh California Aqueduct water each year of the rotation, regardless of the crop; (2) irrigation with saline drainage water on tomatoes and irrigation with fresh water on the subsequent cotton crops; and (3) irrigation with saline water on tomatoes and

on the first subsequent cotton crop, followed by fresh water on the second cotton crop. The treatments were designed such that saline water was always applied to the tomato crop, to obtain the advantage of fruit quality improvement (see Grattan et al., 1987), while also ensuring that the field was irrigated with fresh water for at least one season prior to planting tomatoes in order to reduce the salinity level for tomato seed germination and seedling establishment. The 3-year rotation/irrigation regime was initiated at each of the three possible rotation entry points. Therefore, the study consisted of nine treatments (Table 1) replicated four times in a randomized complete block design.

Each tomato plot contained five 1.7 m (66-inch) beds planted with a single row on each bed, whereas the cotton plots contained eight 1.0 m (40-inch) beds with one row per bed. The two outer beds in all plots were not used for data collection. One variety of tomato (FM 785) and two varieties of cotton (SJ-2 and GC-510) were used. The tomatoes were planted in February or early March and cotton in early April, although the exact date differed from year to year. Both crops were always sprinkler irrigated with fresh water for germination and stand establishment.

Fresh water was applied to all tomato plots prior to first bloom, regardless of treatment. Thereafter for the saline treatments, drainage water was applied at each irrigation. Tomatoes were irrigated on a weekly schedule with the quantity of water applied calculated based on ET estimates from CIMIS weather station ETo value and by a site-specific crop coefficient and on soil water depletion estimates from neutron probe measurements. All cotton plots received fresh water for the first irrigation and then saline treatments received drainage water for all subsequent irrigations. The timing of irrigations in the cotton plots was based upon weekly measurements of leaf water potential. Plots were irrigated when midday leaf water potentials fell below -16 bars for the first irrigation and -18 bars thereafter, with the quantity to be applied calculated in the same way as for the tomato plots. In 1986-89, neutron probe measurements were made before each weekly irrigation in the tomato plots and every two weeks in cotton plots. Flow meters were used to measure the quantity of applied water. Some problems occurred with irrigation during the 1988 season, due to faulty flow meters and inadequate pre-irrigation. These problems were corrected in 1989 and thereafter. In 1990, the irrigation interval was extended in tomatoes from weekly to every 14 days in some cases due to lack of availability of irrigation water. Samples were taken from both types of irrigation water and analyzed to determine EC and contents of major anions, cations and trace elements.

Tomato fruit yield, fruit soluble solids, and citric acid content data were collected at time of harvest. Total above ground biomass of the mature tomato plant was sampled at harvest and partitioned into red fruit, green fruit, and rotten fruit. The amounts of boron, selenium and inorganic salts accumulated in the fruit and vegetative parts were determined. Cotton was harvested and both lint and seed-cotton yield data were collected.

Soil salinity profiles were determined by measuring the electrical conductivity of saturation extracts (EC_e) of soil samples at the end of each season. B, Se, SO_4 , Cl, Na, Ca, and Mg in soil extracts from each plot were also measured at the end of the season for 1987 and 1988, thereafter only EC_e , Se and B were monitored. Soil water-infiltration rates were evaluated in the spring and in the fall of 1989 using a rainfall simulator, courtesy of T. Prichard.

RESULTS AND DISCUSSION:

Cotton Emergence

Stand establishment (number of emerged seedlings per area) was reduced by 40-50% in 1988 in cotton plots that had received saline irrigation water in the previous year. This appeared to be related to severe soil crusting when the plots were sprinkle irrigated to germinate the seeds. No such effect was seen in 1989, 1990 or 1991, presumably because the weather conditions were more favorable for cotton seed germination and a larger volume of water had been applied as a pre-irrigation in these years than in 1988.

Crop Yields

Seed-cotton yields showed no significant response to the irrigation/rotation treatments in any year of the study in either cotton variety (Table 2, GC-510 only) for the first five years (Table 2). The same was true for the percent seed oil (data not shown). In 1991, however, both lint yields (data not shown) and seed cotton yields were significantly reduced up to 15% in those plots irrigated with saline drainage water. This finding was somewhat surprising particularly since cotton is a salt-tolerant crop with a yield threshold EC_e value of 7.7 dS/m (Maas, 1990). However, since cotton is traditionally grown with long-time intervals between irrigations as a means of controlling vegetative growth, it is possible the combined stresses of salinity and water deficit could be antagonistic.

Tomato red-fruit yield was also not significantly affected by treatment (Table 3) for the years 1986-1989. The yield of green fruit in both 1988 and 1989 was significantly lower in the fresh water control than in the FFS or the SFS treatments. This implies that the period of fruit production is extended in the saline treatments, which is probably related to the high levels of supplemental nitrogen present in the saline irrigation water (an average of 90 lbs N/acre-foot of water, data courtesy of Kent Tyler). In 1990, red fruit yields were reduced by 40% in those plots that were irrigated with saline water. There was no significant difference in yield whether the plots received drainage water one out-of-three or two out-of-three years. This may have been due, in part, to longer intervals between irrigations in 1990. This could have stressed the drainage water tomatoes significantly more than the fresh water tomatoes. The gradual increase in salt and boron

concentrations in the soil profile may also have been a partial factor, however, it could not account entirely for the dramatic yield reduction.

In 1991, yields of red tomatoes from plots irrigated with drainage water one out-of-three years and two out-of-three years were only 91% and 83% of these from control plots, but only the mean for the two-year salinity treatment was significantly different from the control.

In 1992, respective yields from plots treated with saline drainage water were 94% and 78% those from nonsaline controls, but again only the later treatment was significantly different.

Tomato Fruit Quality and Tissue Analysis

There were no significant treatment differences observed in fruit quality as described by pH, and fruit color, but percent total solids, soluble solids (as indicated by Brix) and percent citric acid were enhanced by saline water application in most years (Table 4). Salinity's enhancement of soluble solids in the fruit was significant (5% level) in 1987, 1989, and 1990 in those plots that received drainage water one out-of-three and in 1989, 1990, 1991 and 1992 in those plots that received drainage water two out-of-three years. In 1988, it is probable that the abnormally high solids in the fresh water plots were due to water stress caused in part by malfunctioning of the flow meter used in the fresh water irrigation systems, which led to under irrigation of these plots and thus inadvertent stress imposed on the plants.

Water Infiltration

No significant differences among treatments could be detected in water infiltration rates as measured with the rainfall simulator in spring and fall of 1989. Infiltration rates were not measured other years.

Soil Chemical Quality

The data for EC_e , B_e , and Se_e are presented in the previous years of the UC Salinity/Drainage Task Force annual report and is therefore not reported here. The data were plotted as a function of time in order to reflect the transient nature of the soil profile chemistry. The 0-15 cm portion of the profile was the most responsive to irrigation treatments. That is, the concentration of salts and boron change rapidly and concentration differences from year to year are more extreme than at lower depths in the profile. In regards to EC_e and boron, the data indicates that in general in the soil levels from 0-60 cm, one year of fresh water applied to previously salinized plots reduced the salinity levels significantly and that a second year of fresh water would reduce levels even further. Fresh water irrigation did not however, return concentrations to their original levels, i.e., those of the control plots where only fresh water was applied. At the 60-140 cm depths, EC_e and boron levels were much less responsive to fresh water irrigation and over

years gradually increased. These factors may limit the feasibility of this cyclic practice over the long-term. The strategy could be modified by including more years of fresh water in the irrigation rotation or by increasing the pre-plant fresh water irrigation each season.

Soil selenium is different from that of salinity (EC_e) and boron. The data indicate that water extractable selenium (presumably mostly selenate) appears to be more readily leached than the majority of salts. If this trend continues, then selenium in the drainage water will not be as a limiting factor to its reuse as salinity and boron. It is possible, however, that some of the selenium in the drainage water that is applied to the plots may be reduced to selenite or converted to some organic form. If this occurs to any large extent, the mobility of selenium in the soil profile may be over predicted.

Crop Se and B Accumulation

Saline drainage water increased the concentrations of both B and Se in tomato leaf and fruit tissue (data not shown), although the magnitude of the differences varied from year to year. Boron and Se concentrations were higher in the leaf tissue than in the fruit. Fruit Se concentrations were less than 250 ug/kg and were not considered to be a health hazard by the Department of Health. There is no question that the high levels of sulfate in the soil and drainage water played an important role in reducing selenate uptake by the plant. Drainage water increased the concentrations of both these elements in the tissue but unlike B, Se showed similar increases in both leaf and fruit concentrations following drainage water application. Boron, on the other hand, increased in the leaf tissue in response to drainage water application substantially more than in the fruit. For any given year, contrasts between the one (FFS) and two (SFS) year saline treatments were not significant. However, when data were combined for 1988-90, leaf B and fruit Se were significantly higher in the SFS than FFS treatment. In addition, leaf B concentrations increased steadily over the years, which may reflect the steady accumulation of B in the soil profile during these years.

SUMMARY:

Saline drainage water ($EC_i = 7.3$ to 7.7 and 5 mg/L B) was successfully used to irrigate processing tomato, after the crop reached the first bloom stage, in a three-year rotation with cotton for seven years. However, since salts and B accumulated in the soil profile over the years, particularly at depths below 60 cm, the feasibility of continuing to achieve success with this irrigation strategy is dependent, in part, upon the ability to maintain a favorable salt and B balance in the soil. This can most likely be achieved by increasing the pre-irrigation water requirements, but not to the extent to where this strategy no longer conserves good quality water. Furthermore, the accumulation of B in the soil under this reuse strategy may affect the future utility of the land

until soil B is reduced to a satisfactory level. For example, most tree and vine crops are very sensitive to B and produce injury symptoms at concentrations as low as 0.5 mg/L in the soil solution.

Tomato fruit quality (i.e., soluble solids) was often improved by saline drainage water applications. However these benefits were sometimes offset by reduced yields. Nevertheless, growers that produce fruit with higher soluble solids are sometimes paid higher prices that partly compensate for mild reductions in yield.

Our work, as well as work by others that were funded by the UC Salinity/Drainage Task Force, demonstrated that the tomato crop partitions most of the Se that is translocated to the shoot in the leaves and stems and away from the fruit. Although irrigation with drainage water increased fruit Se, concentrations were below those considered to be a health threat.

Use of saline drainage water for irrigation, particularly in a cyclic manor where the drainage water has a high sodium adsorption ratio, may produce adverse soil physical conditions (e.g., crusting and reduced water infiltration). In our study, we did not find any reductions in water infiltration but cotton stands (number of emerged seedlings per area) were reduced by 40 to 50% in 1988 in all plots that were irrigated with saline drainage water the year before. This was not found in any of the subsequent years.

In conclusion, if a favorable balance of salt and B can be effectively maintained within the root zone while maintaining an overall savings in good quality water, then irrigation with saline drainage water (EC = 7.3 to 7.7 and 5 mg/L B) one out-of-three years, utilizing the proposed strategy and rotation, is feasible.

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Table 1. Irrigation/Rotation Experimental Treatments for the Long-Term Cyclic Drainage Water Use Experiment

Irrigation Treatment		Irrigation/Rotation Treatment		
		Year 1	Year 2	Year 3
Fresh Water all 3 Years	1.	F _t	F _c	F _c
	2.	F _c	F _t	F _c
	3.	F _c	F _c	F _t
One Year Saline Water (on Tomato Crop)	4.	S _t	F _c	F _c
	5.	F _c	S _t	F _c
	6.	F _c	F _c	S _t
Two Year Saline Water (on Tomato and the following Cotton Crop)	7.	S _t	S _c	F _c
	8.	F _c	S _t	S _c
	9.	S _c	F _c	S _t

F = fresh California Aqueduct Water; S = saline drainage water; t = tomatoes; c = cotton

Table 2. Seed Cotton Yields at the end of each Season

Seed Cotton Yields (mT/ha)							
Year							
Treatment	1986	1987	1988	1989	1990	1991	
						SJ-2	510
FFF	5.9	5.6	3.6	6.0	3.6	6.7	6.2
FFF	5.9	5.6	3.6	5.9	3.5	6.9	6.6
SFF	—	—	3.5	5.5	3.5	6.1	5.6
FSF	—	5.7	3.0	5.8	3.7	6.4	6.4
SSF	—	—	3.1	5.6	3.8	5.8	5.5
FSS	—	5.7	3.4	5.9	3.7	6.1	5.6

Table 3. Red tomato Fruit Yields at the end of each Season

Tomato Yields (MT/Ha)

Irrigation Treatment	Year						
	1986	1987	1988	1989	1990	1991	1992
Non-saline	69	101	58	105	88a	78a	80a
Saline (one-out-of-three-years)	67	102	79	92	54b	71ab	75ab
Saline (one-out-of-three-years)	—	—	63	88	51b	64b	62bc

Table 4. Tomato Fruit Quality as Influenced by the Various Treatments

Tomato Fruit Quality

Treatment	1986		1987		1988		1989		1990	1991	1992
	°Brix	%Citric	°Brix	%Citric	°Brix	%Citric	°Brix	%Citric	°Brix	°Brix	°Brix
FFF	5.1	na	5.4b	.34b	6.7a	.39	5.7b	.42b	5.2b	5.5b	5.6b
FFS	5.2	na	5.6a	.38a	6.0b	.41	6.0a	.48a	5.9a	5.8a	5.7b
SFS	—	—	—	—	6.5a	.41	6.0a	.45a	6.1a	6.3a	6.0a
	n.s.		*	*	*	n.s	*	*	*	*	*

* Different letters within a column indicate means differ at the 5% level.

— not far enough into rotation for treatment to be fully established.

na data not available.