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Use of Saline Drainage Water for Irrigation: Imperial Valley Study*

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ABSTRACT

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It is contended that there is potential to expand irrigated agriculture through the increased use of saline waters for irrigation. Two kinds of evidence are given to support this contention. Literature is cited to document the successful use of saline waters for irrigation around the world, even when conventional management was employed. Results of a field test are presented to document the feasibility of facilitating the use of saline water for irrigation through the development of new crop/water management strategies and practices.

INTRODUCTION

A U.N. report concluded that little expansion in irrigated agriculture is possible because the readily suitable lands and waters are nearly fully developed (U.N. World Food Conf., 1974). This conclusion is questioned because very conservative standards were used to assess the fitness of water and soil for irrigation and only conventional criteria and procedures of producing irrigated crops were considered in the evaluation. Irrigated agriculture could be expanded if saline waters were used. Recent studies and evaluations indicate that waters previously thought unsuitable for irrigation can often be used successfully to grow crops without hazardous long-term consequences to crops or soils. The adoption of new crop and/or water management strategies could further

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enhance the feasibility of using saline waters for irrigation. Considerable quantities of saline water are available, including drainage waters from irrigation projects and shallow groundwaters, in many places throughout the world, including the United States, the Soviet Union, Pakistan, India, Egypt and Australia. Use of such water would not only permit the expansion of irrigated agriculture but would also reduce drainage disposal and associated pollution problems as well (Rhoades, 1983).

This paper presents evidence of the potential to use saline water for irrigation, along with a management strategy to enhance such use. A brief review of relevant literature is given to document the successful use of saline waters for irrigation by conventional means, followed by results of a relatively long-term field test where saline drainage water was used for irrigation.

REVIEW OF LITERATURE

Some have claimed that sea water can be used directly for irrigation (Boyko, 1967; Epstein and Norlyn, 1977), but the reported data are far from convincing. Ayers et al. (1952) were able to grow barley in field plots without yield reduction with irrigation water salinities as high as two-thirds the concentration of sea water (20 000 mg/L), but only when non-saline water was used for stand establishment. Dhir (1976) reported the use of irrigation waters with electrical conductivities (EC) as high as 15 dS/m for wheat production in India. Reports such as this one can easily be misinterpreted because the wheat was grown in a climate with an annual monsoon which provided extra quantities of non-saline water during the growing season for both transpiration and leaching.

In the U.S., extensive areas of alfalfa, grain sorghum and wheat are irrigated in the Arkansas Valley of Colorado with water containing not less than 1500 mg/L of total dissolved solids (TDS) and up to 5000 mg/L (Miles, 1977). In the Pecos Valley, water averaging 2500 mg/L has been used for irrigation for decades (Moore and Hefner, 1976). Paliwal (1972) gives a number of examples of continuing irrigation in India with waters of even higher salinity. Hardan (1976) reports the irrigation of pear trees in Iraq with waters ranging up to 4000 mg/L without yield reduction. Frenkel and Shainberg (1975) and Keren and Shainberg (1978) reported that cotton is grown commercially in Israel with water having an EC of 4.6 dS/m ($\sim$2800 mg/L). The report that 10 t/ha yields of alfalfa are achieved in the USSR with water of 12 500 mg/L (Bressler, 1979) may be the result of poor translation or interpretation. Data on cotton irrigation from the same source are more consistent with experience from the U.S.; good yields were obtained in Uzbekistan over long-term periods with waters having 5000–6000 mg/L total dissolved solids. Jury et al. (1978) grew wheat in lysimeters with waters of up to 7.1 dS/m EC without deleterious effects on yield. Pillsbury and Blaney (1966) concluded that the upper limit for the salinity level (EC) of an irrigation water is about 7.5 dS/m. Shalhevet and Kamburov (1976) in their worldwide survey of irrigation and salinity found that waters of up to 6000 mg/L were being used successfully.

Though this number of documented reports on the successful use of brackish water for irrigation is relatively limited, these examples are sufficient to support the premise that water more saline than presently termed usable in conventional water classification schemes can be successfully used for irrigation. Waters having salinities of up to about 8 dS/m EC or 6000 mg/L TDS are apparently usable with conventional management.

Indirect evidence of the potential to use saline drainage waters for irrigation can be obtained from computer models developed to predict soil water composition resulting from irrigation, and models developed to relate crop response to soil salinity. The suitability of a saline water for irrigation should be evaluated by taking into account the specific conditions of use, including the crop grown, soil properties, irrigation management, cultural practices, and climatic factors. The assessment of suitability should ideally consist of (1) predicting the composition, osmotic potential and matric potential of the soil water of the rootzone, both in time and space, resulting under the specific conditions of management and climate; and (2) interpreting such information in terms of how suitable the resulting soil conditions are for rooting and how the crop(s) in question would respond to such soil and climatic conditions (Rhoades, 1972).

A computer model for assessing water suitability for irrigation which employs the above approach has been developed (Rhoades and Merrill, 1976; Rhoades, 1984). The accuracy of the predicted soil water salinities, sodicities and osmotic potentials have been shown to be acceptable (Oster and Rhoades, 1975, 1977). The assumption that crop production is predictable from integrated osmotic and matric potentials or from different indices of soil salinity dependent on irrigation management has been demonstrated (Ingvalson et al., 1976; Letey et al., 1985; Bresler, 1987; Dinar et al., 1986). Available crop tolerance to salinity data (Maas, 1986) have been shown to be acceptable in such predictions (Letey et al., 1985; Bresler, 1987).

When one applies such models to the assessment of the suitability of saline waters for irrigation, one concludes that typical drainage waters can generally be used for irrigation, of course with crop selectivity being limited to those of appropriate tolerance (Rhoades, 1977; Dinar et al., 1986). These predictions support the empirical results and reports cited above of such feasibility.

CROP/WATER MANAGEMENT STRATEGY TO FACILITATE THE USE OF SALINE WATERS FOR IRRIGATION

Typically farmers will not use brackish water for irrigation if access to water of lower salinity is available, unless the brackish water can be used without losses in yield and cropping flexibility, or significant changes in farming practices. Most irrigation projects have a developed supply of relatively low salinity water. Typically, forty percent of it is discharged as drainage water (Van Schilfgaarde, 1974). This drainage water often moves to the underlying shallow groundwater. A proposed management strategy which applies to such projects, and which meets the above-mentioned farmer requirements, is to substitute saline water (drainage or shallow groundwater) for the non-saline water when irrigating salt-tolerant crops grown in the rotation when they are in a non-sensitive growth stage; and to use the non-saline water at the other times. The timing and amount of substitution will vary with the quality of the two waters, the cropping pattern, the climate, and the irrigation system. Obviously, the maximum soil salinity in the rootzone that can result from continuous use of saline water will not occur when such water is used for only a fraction of the time. Simple calculations will show that a soil will not generally become unduly saline from use of a saline water for a part of a single irrigation season and often not for several seasons. Whatever salt buildup occurs in the rootzone from irrigating with the saline water is alleviated in the subsequent cropping period, when a more sensitive crop is grown using the low-salinity water for irrigation. Furthermore, the yield of the sensitive crop should not be reduced, if proper preplant irrigations and careful management are used during germination and seedling establishment to leach salts out of the shallow soil depths. Subsequent irrigations given after the establishment of stand will leach these salts farther down in the soil profile ahead of the advancing root system and "reclaim" the soil in preparation for use of the saline water again to grow a suitably tolerant crop. This cyclic use of "low" and "high" salinity waters prevents the soil from becoming excessively saline while permitting, over the long period, substitution of saline water for a low-salinity water for a large fraction (up to about 50%) of the crop water requirements (Rhoades, 1983, 1984, 1985).

FIELD TEST OF SALINE DRAINAGE WATER FOR IRRIGATION

The crop/water management strategy described above was recently tested for four years under actual commercial-farming conditions in a 20 ha field located in the Imperial Valley of California. Two cropping rotations were used. One was a two-year rotation of wheat, sugarbeets, and cantaloupe melons, which was repeated for a second cycle. This rotation will be referred to as the "successive crop" rotation. In this rotation, Colorado River water ($\sim$900 mg/L TDS) was used for the preplant and early irrigations of wheat and sugarbeets and for all irrigations of the melons. The remaining irrigations were with drainage water ($\sim$4.0 dS/m EC). The compositions of these two waters are given in Table 1. The other rotation consisted of two crops of cotton followed by one crop of wheat and then by almost two years of continuous alfalfa. This rotation is referred to as the "block" rotation. In this rotation, drainage water was used for the irrigation of both cotton crops after seedling establishment,

TABLE 1

Average compositions of Colorado River and drainage waters

Water/ Statistics	EC ($dS\ m^{-1}$)	SAR[a] ($(mmol_c\ L^{-1})^{1/2}$)	Solute concentration ($mmol_c\ L^{-1}$)								
			B[b]	Ca	Mg	Na	K	Alk	SO_4	Cl	NO_3
Colorado River											
Number of samples	50	50	46	48	50	50	49	45	40	48	11
Mean value	1.25	3.2	0.31	4.1	2.6	5.7	0.11	2.6	6.6	3.1	0.05
Standard deviation	0.13	0.5	0.12	1.2	0.3	1.0	0.04	0.5	0.9	0.5	0.02
Standard error of mean	0.02	0.07	0.02	0.2	0.04	0.1	0.01	0.07	0.1	0.1	0.01
Alamo River											
Number of samples	34	33	32	31	34	34	33	34	20	31	16
Mean value	4.0	8.2	0.8	10.3	8.9	25.1	0.32	4.4	22.2	18.4	0.7
Standard deviation	0.3	1.5	0.3	2.1	1.2	4.4	0.05	1.3	4.0	2.1	0.6
Standard error of mean	0.06	0.3	0.06	0.4	0.2	0.7	0.01	0.2	0.9	0.4	0.2

[a]SAR: Sodium adsorption ratio $= Na/\sqrt{(Ca+Mg)/2}$, where all solute concentrations are in $mmol_c\ L^{-1}$.
[b]Concentration in $mg\ L^{-1}$.

while Colorado River water was used during seedling establishment. For the wheat and alfalfa crops, only Colorado River water was used. It was hypothesized that wheat would withstand the salinity developed in the soil from irrigating the previous two cotton crops with the saline drainage water and would yield well when irrigated with Colorado River water. Enough desalination of the soil during the wheat crop was expected to occur during irrigations with Colorado River water to permit alfalfa to be grown subsequently without any loss of yield from excess salinity.

The average amounts of water applied to each crop and the totals over the entire four-year period are given in Tables 2 and 3 for the "successive" and "block" rotations, respectively. These data include all water applied, including that used for preplant irrigations and land preparation purposes. Rainfall was insignificant. These data show that substantial amounts of drainage water were substituted for Colorado River water in the irrigation of these crops. The estimated amounts of water consumed by the crops through evapotranspiration and lost as deep percolation are given in Table 4 by individual crop and by succession of crops for both rotations. It was assumed that consumptive use was the same in all treatments, since no substantial yield differences occurred among treatments.

Crop yields in the "successive" and "block" rotation(s) are given in Tables

TABLE 2

Amounts (mm) of Colorado and Alamo River waters used for irrigation in the "successive" crop rotation

Treat-ment[a]	1982 Wheat				1984 Wheat			
	Colo. R.	Alamo R.	Total	% Alamo R.	Colo. R.	Alamo R.	Total	% Alamo R.
C	548(3)[b]	0	548(3)	0	823(4)	0	823(4)	0
Ca	417(5)	129(1)	545(4)	24	431(2)	396(2)	827(2)	48
cA	131(1)	425(4)	556(4)	76	307(2)	526(2)	833(3)	63
	1983 Sugar beets				1985 Sugar beets			
	Colo. R.	Alamo R.	Total	% Alamo R.	Colo. R.	Alamo R.	Total	% Alamo R.
C	1268(5)	0	1268(5)	0	1400(4)	0	1400(4)	0
Ca	712(1)	536(2)	1249(2)	43	711(3)	663(3)	1374(5)	48
cA	448(3)	800(3)	1248(4)	64	491(2)	873(4)	1364(4)	64
	1983 Cantaloupes				1985 Cantaloupes			
	Colo. R.	Alamo R.	Total		Colo. R.	Alamo R.	Total	
C	626(7)	0	626(7)		360(6)	0	360(6)	
Ca	623(2)	0	623(2)		354(4)	0	354(4)	
cA	628(3)	0	628(3)		346(4)	0	346(4)	
	Complete rotation							
	Colo. R.	Alamo R.	Total	% Alamo R.				
c	5025(12)	0	5025(12)	0				
Ca	3248(9)	1724(5)	4971(11)	35				
cA	2351(7)	2624(3)	4975(10)	53				

[a]C = Colorado River water and solely for irrigation; Alamo River water used for irrigation in relatively smaller (Ca) and larger (cA) amounts.
[b]Number in parentheses is standard error of mean.

5 and 6, respectively. No significant yield losses occurred for the wheat and sugarbeet crops in either cycle of the "successive" rotation from substituting drainage water for Colorado River water after seedling establishment (even in the greater amount; 65–75%, treatment cA). The mean yield of cantaloupe seed obtained in the cA treatment plots was about 10% lower than the control, but the difference was not statistically significant. The yields of the fresh-market melons (numbers of cartons of cantaloupes obtained by commercial harvest operations) in 1985 were higher in the Ca and cA treatments than in the C treatment, but they were not significantly different (see Table 5). Hence,

TABLE 3

Amounts[a] (mm) of Colorado and Alamo River waters used for irrigation in the "block" rotation

Treatment[b]	1982 Cotton				1983 Cotton			
	Colo. R.	Alamo R.	Total	% Alamo R.	Colo. R.	Alamo R.	Total	% Alamo R.
C	1306(19)[c]	0	1306(19)	0	1177(6)	0	1177(6)	0
cA	515(12)	774(30)	1289(42)	60	617(4)	545(3)	1162(6)	47
A	0	1187(25)	1187(25)	100	0	1149(7)	1149(7)	100
	1984 Wheat				1984-1985 Alfalfa			
	Colo. R.	Alamo R.	Total		Colo. R.	Alamo R.	Total	
C	823(8)	0	823(8)		2048(6)	0	2048(6)	
cA	798(2)	0	798(2)		2058(7)	0	2058(7)	
A	795(5)	0	795(5)		2029(16)	0	2029(16)	
	Complete rotation							
	Colo. R.	Alamo R.	Total	% Alamo R.				
C	5372(8)	0	5372(8)	0				
cA	3995(18)	1332(34)	5327(50)	25				
A	2824(17)	2336(30)	5160(42)	45				

[a]Includes pre-plant water applications.
[b]C = Colorado River water used solely for irrigation; Alamo River water used for irrigation in relatively smaller (Ca) and larger (cA) amounts after seedling establishment with Colorado River water.
[c]Value in parentheses is standard error of mean.

no significant yield loss was observed from growing cantaloupes using Colorado River for irrigation in the land previously salinized from the irrigation of wheat and sugarbeets with drainage water. There was no loss in the yields of the crops grown in the "block" rotation from substituting drainage water for Colorado River water for the irrigation of the two cotton crops after seedling establishment. In the first cotton crop (1982), lint yield was not reduced even when saline water was used for all irrigations, including the preplant and seedling establishment periods (treatment A). There was no significant loss in lint yield in the second cotton crop (1983) from use of drainage water for the irrigations given following seedling establishment which was accomplished using Colorado River water (the recommended strategy treatment, cA), although yield was lower this year. There was a significant and substantial loss of lint yield, as expected, where the drainage water was used solely for irrigation (treatment A). This yield reduction was caused primarily by a loss of stand that occurred this second year because salinity was excessively high in the seedbed during the establishment period. No loss in yield of wheat grain or

TABLE 4

Estimated amounts (mm) of water used in evapotranspiration and lost as deep percolation

Crop	V_{et}[1]	V_{iw}[2]	V_{dw}[3]	LF[4]	Accum.[5] V_{et}	Accum. V_{iw}	Accum. V_{dw}	Accum. LF
"Successive" crop rotation								
1982 wheat	655	556	−99	−0.18	655	556	−99	−0.18
1983 Sugar beets	1029	1247	218	0.18	1684	1803	119	0.07
1983 melons	427	627	201	0.32	2111	2431	320	0.13
1984 wheat	688	833	145	0.17	2799	3264	465	0.14
1985 Sugar beets	1074	1364	290	0.21	3873	4623	754	0.16
1985 melons	427	345	−81	−0.24	4300	4973	673	0.14
"Block" rotation								
1982 cotton	988	1288	300	0.23	988	1288	300	0.23
1983 cotton	1034	1161	127	0.11	2022	2451	429	0.18
1984 wheat	688	798	109	0.14	2710	3249	541	0.17
1985 alfalfa	2062	2057	−5	−0.00	4770	5306	536	0.10

[1]Evapotranspiration estimated from pan evaporation and crop factors at Brawley, California.
[2]Total amount of water applied for irrigation.
[3]Estimate of deep-percolation drainage water i.e., $V_{iw} - V_{et}$.
[4]Estimate of leaching fraction (LF), i.e., V_{dw}/V_{iw}.
[5]Accumulated over entire experimental period.

TABLE 5

Yields of crops in "successive" rotation

Treatment[1]	Crop/Year		
	wheat/1982[2]	sugar beets/1983[3]	cantaloupes/1983[4]
C	8.1(0.1)[6]	9.6(0.2)	439(13)
Ca	8.1(0.2)	9.6(0.4)	430(11)
cA	8.3(0.1)	9.2(0.2)	398(16)
	wheat/1984[2]	sugar beets/1985[3]	cantaloupes/1985[5]
C	7.9(0.2)	9.2(0.2)	115(5)
Ca	7.8(0.2)	9.2(0.2)	142(8)
cA	8.0(0.2)	8.7(0.2)	139(12)

[1]C = Colorado River water used solely for irrigation; Alamo River water used in relatively smaller (Ca) and larger (cA) amounts, after seedling establishment with Colorado River water for wheat and sugar beets. Cantaloupes only irrigated with Colorado River water.
[2]Tons of grain per hectare.
[3]Tons of sugar per hectare.
[4]Kilograms of seed per hectare.
[5]Commercial yield in number of cartons per plot; plot size = 229×11.6 m^2 = 0.26 ha.
[6]Value in parentheses is standard error of mean; six replicates.

TABLE 6

Yields of crops in "block" rotation

Treatment[1]	Crop/Year			
	Cotton/1982[2]	Cotton/1983[2]	Wheat/1984[3]	Alfalfa/1985[4]
C	1.47(0.04)[5]	1.15(0.06)	7.7(0.1)	17.5(0.9)
cA	1.48(0.03)	1.12(0.05)	7.7(0.1)	15.7(1.1)
A	1.55(0.02)	0.74(0.03)	7.6(0.1)	16.6(0.7)

[1]C = Colorado River water used solely 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.
[2]Commercial yield of lint, tons per hectare.
[3]Tons of grain per hectare.
[4]Tons of dry hay per hectare.
[5]Value in parentheses is standard error of mean; six replicates.

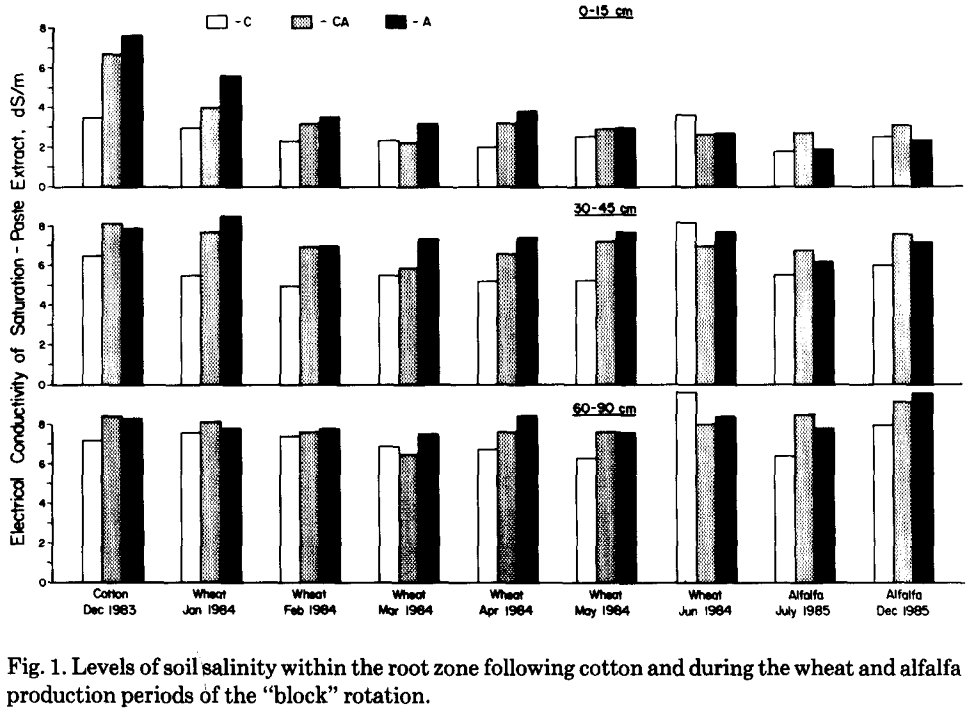

Fig. 1. Levels of soil salinity within the root zone following cotton and during the wheat and alfalfa production periods of the "block" rotation.

alfalfa hay occurred in the "block" rotation associated with the previous use of drainage water on these same lands, under these conditions in which the wheat and alfalfa crops were irrigated with Colorado River water.

Crop quality was never inferior and often was superior, when the crops were

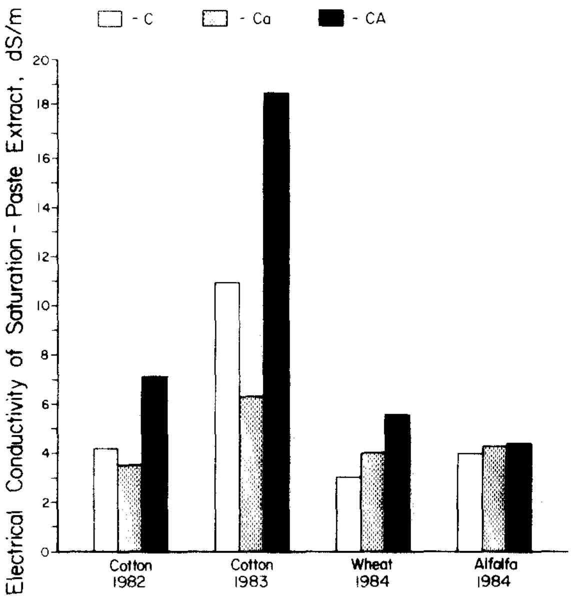

Fig. 2. Levels of soil salinity in the seedbed at time of germination of each crop in the "block" rotation.

grown using drainage water for irrigation or on the land where it had previously been used. These quality data are given elsewhere (Rhoades et al., 1988a).

Figures 1 and 2 show the soil salinity during the field trials at various times in the "block" rotation to illustrate how salinity increased from irrigating the cotton crops with drainage water and was lowered by the pre-irrigation of cotton and the irrigation of wheat and alfalfa with Colorado River water. More detailed data on soil salinity and sodicity (including that for the "successive" rotation) are given elsewhere (Rhoades et al., 1988b). These data are given to demonstrate that soil salinity was kept within acceptable limits for seedling establishment and the subsequent growth of the crops grown in the "block" rotation when the recommended strategy was employed. These results obtained under actual farming conditions support the practicality of the recommended cyclic crop and water strategy to facilitate the use of saline waters for irrigation.

SUMMARY AND CONCLUSIONS

Rational water assessment procedures indicate that waters of higher salinities than customarily classified as suitable can be used effectively for irrigating selected crops with conventional methods of management. Customary water quality standards appear to have been based on the availability of good quality water and are too conservative. Worldwide literature documents that relatively saline waters can be used for irrigation. The use of saline waters for irrigation can be enhanced if a dual rotation (crop and water) system of management is used. In this management system saline water is substituted for low-salinity irrigation water without significant yield reduction, loss in cropping flexibility, or change in current farming operations at certain times during the crop rotation. Salt-sensitive crops (lettuce, alfalfa, etc.) in the rotation are irrigated with low-salinity water while saline water is applied to the salt-tolerant crops (cotton, sugarbeets, wheat, etc.). For the tolerant crops, the switch to saline water usually occurs after seedling establishment; preplant and initial irrigations are made with low salinity water. This strategy is verified by data from the field experiment. A way to operate the strategy so that the drainage water salinity does not increase in time and eventually terminate the re-use is discussed in another paper (Rhoades, 1989). An alternative strategy often advocated to facilitate the use of saline waters for irrigation is to blend them with water of low salinity before use. A comparison of these two strategies (cyclic use versus blending) is also discussed by Rhoades (1989).

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