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REDUCING WATER QUALITY DEGRADATION THROUGH MINIMIZED LEACHING MANAGEMENT

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ABSTRACT

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The U.S.A. has adopted a policy of enhancing water quality and of conserving natural resources. The concept of minimized leaching has been advanced to help meet these goals by reducing salinity pollution from irrigated agriculture. It has received considerable attention by those concerned with management of water resources and is promoted by some as a generally applicable method for minimizing salinity pollution. This paper reviews the basis of the concept and identifies the conditions under which minimized leaching will and will not enhance water quality.

INTRODUCTION

With irrigation water containing from 0.05 to 3.5 metric tons of salt per 1000 m^3 and crops requiring annual applications of 6200 to 9300 m^3 water/ha to meet evaporation, from 0.3 to 32 metric tons of salt may be added per hectare to irrigated soils annually. The concentration of soluble salts in soils increases because evaporation and transpiration remove water only, leaving the salt behind. Unless this excess salt is leached out of the rootzone, soluble salts will accumulate in irrigated soils to the point that crop yields will decrease. In arid regions, rainfall is insufficient to remove these salts; thus more water must be applied than is required to meet evapotranspiration needs of the crop. This additional water is referred to as the leaching requirement (LR) (U.S. Salinity Laboratory Staff, 1954). The excess water drains from the soil rootzone and percolates to the groundwater, which often flows into rivers. In either case, the quality of the receiving water is usually degraded. With subsequent cycles of diversion, use, percolation and return flow of such waters, degradation progresses.

The U.S.A. has adopted a policy of enhancing water quality and of conserving natural resources. Minimized leaching may help to meet these goals by reducing salinity pollution from irrigated agriculture (Rhoades et al., 1973, 1974; Van Schilfgaarde et al., 1974). The concept of minimized leaching has received considerable attention by those concerned with management of water resources and is promoted by some as a generally applicable method for minimizing salinity pollution while sustaining crop productivity. As compared with high leaching, minimized leaching will always reduce the salt discharged from rootzones but will not always reduce degradation of the quality of the receiving water. Our purpose here is to review the basis of the concept and to identify the conditions for which minimized leaching will and will not reduce pollution in arid zone irrigation.

REDUCTION OF SALT DISCHARGE FROM IRRIGATED SOILS WITH MINIMIZED LEACHING

Research and modeling studies at the U.S. Salinity Laboratory (Rhoades et al., 1973, 1974; Oster and Rhoades, 1975) demonstrated that minimizing the leaching fraction (LF) reduces the application of salts to the soil and the return of salts in drainage from the rootzone of irrigated crops; it maximizes the precipitation of applied Ca, HCO_3 and SO_4 salts as carbonates and gypsum minerals in the soil; and it minimizes the "pick-up" of weathered and dissolved salts from the soil. In these studies, salt budgets were determined for soil-filled lysimeters during 3 years of alfalfa production using eight river waters, differing drastically in total salinity and in ionic composition, at LF values of 0.1, 0.2, and 0.3. Results of these studies are shown in Table I for a consumptive use of 61 cm/year. Table I shows the salt loads in the irrigation ($V_{iw}C_{iw}$) * and drainage ($V_{dw}C_{dw}$)* waters, together with the net salt balance ($SB = V_{dw}C_{dw} - V_{iw}C_{iw}$). These data show that the salt load from the rootzone can be reduced by from about 2 to 12 metric tons/ha/year by reducing the LF from 0.3 to 0.1.

The reduction in salt return shown in Table I is achieved in three ways. Less salt is discharged with reduced leaching because less irrigation water, and hence salt, is applied. The percent reduction in salt discharge due to reduced application is

$$100\,(V_H - V_L)/V_L, \qquad (1)$$

where V_H and V_L are volumes of irrigation water applied with high and low leaching, respectively. Reduced leaching reduces salt discharge still further because the fraction of *applied salts* that precipitate in the soil increases. A further benefit is that fewer additional salts are picked up from the weathering and dissolution of soil minerals. The latter two benefits are demonstrated in Table II where the net effects of soil mineral weathering and dissolution (S_m) and salt precipitation (S_p), as determined in the lysimeter experiment,

* V and C refer to volume and concentration, respectively; iw and dw refer to irrigation and drainage waters, respectively.

TABLE I

Salt burdens of applied waters ($V_{iw}C_{iw}$) and drainage waters ($V_{dw}C_{dw}$), differences (SB), and potential for reducing salt return, metric tons/ha/year*

River	Salinity**	Leaching fraction									Reduction in salt return***
		0.1			0.2			0.3			
		$V_{iw}C_{iw}$	$V_{dw}C_{dw}$	SB	$V_{iw}C_{iw}$	$V_{dw}C_{dw}$	SB	$V_{iw}C_{iw}$	$V_{dw}C_{dw}$	SB	
Feather	1.0	0.67	1.28	+0.60	0.76	2.33	+1.57	0.87	3.36	+2.49	2.08
Grand	10.1	6.12	4.46	-1.66	6.90	6.14	-0.76	7.88	8.29	+0.40	3.83
Missouri	9.1	5.89	5.42	-0.47	6.63	6.83	+0.20	7.59	8.36	+0.76	2.93
Salt	14.3	10.15	9.23	-0.92	11.42	11.76	+0.34	13.06	14.76	+1.70	5.53
Colorado	14.1	8.29	6.23	-2.08	9.32	8.94	-0.38	10.66	10.55	-0.11	4.32
Sevier	20.5	13.19	10.82	-2.37	14.87	14.27	-0.60	17.00	17.67	+0.67	6.85
Gila	31.7	20.36	18.73	-1.64	22.94	23.39	+0.45	26.23	27.80	+1.57	9.07
Pecos	37.5	21.19	12.92	-8.27	23.86	18.12	-5.73	27.28	24.82	-2.46	11.89

* From Rhoades et al. (1974)
** Total concentration (meq/l).
*** The difference in salt output in drainage water between that achieved with leaching fractions of 0.3 and 0.1 assuming a consumptive use requirement of 91 cm/year.

TABLE II

Net effect of LF on (S_m-S_p) for six representative river types expressed as percentage of salt input*

River	100 $(S_m-S_p)/V_{iw}C_{iw}$		
	0.1 LF	0.2 LF	0.3 LF
Feather	+180	+271	+348
Missouri	-9	+5	+13
Colorado	-24	-3	+5
Salt	-10	+6	+12
Sevier	-25	-8	-3
Pecos	-33	-21	-10

* From Rhoades et al. (1974); on meq/l basis.

are given in terms of percentage of the salt load of the irrigation waters ($V_{iw}C_{iw}$). These data show that weathering and dissolution are less and precipitation is greater as the LF decreases.

The experimental data of Table I and II agree with those calculated on the basis of solubility of soil calcium carbonate and gypsum, ion-pair and solute activity theory, taking into account the compositions of the irrigation waters, leaching fractions, soil carbon dioxide partial pressures, and water uptake pattern of the crop (Oster and Rhoades, 1975; Rhoades and Merrill, 1976). These comparisons show that salt precipitation and dissolution reactions can be modeled and resultant soil and drainage water compositions can be adequately predicted for different leaching fractions.

The preceding analyses and data clearly demonstrate that decreasing the leaching fraction can significantly decrease the salt burden of drainage waters from rootzones. Where the drainage waters can be intercepted before returning to surface or groundwater bodies, volume and salt load of drainage can be reduced substantially with reduced leaching. Illustrative of such a situation is the Wellton—Mohawk Project in Arizona where the drainage water is collected by pumps and conveyed in discharge canals to a plant for desalinization (see Table III). With reduced leaching, water diversion into the project could be reduced by 227×10^6 m^3, salt return could be reduced by 324 000 metric tons, return flow could be reduced by 227×10^6 m^3, and the drainage water could be concentrated to the point that it would have nearly no remaining value for irrigation.

LIMITATIONS OF MINIMIZED LEACHING FOR REDUCING SALINITY POLLUTION

While reduced leaching will always reduce the salt discharged from the rootzone, it may not always reduce degradation of the quality of the receiv-

TABLE III

Predicted effect of reduced leaching fraction on salt and water balance of the Wellton—Mohawk Project. Colorado River water containing 158 metric tons of salt/1000 m^3 is applied annually to 26 305 ha to meet the estimated consumptive use of 370 × 10^6 m^3

Item	Unit	High LF (0.42)	Low LF (0.10)
(S_m-S_p)*	%	+8	-25
V_{iw}**	m^3	638 × 10^6	411 × 10^6
V_{dw}**	m^3	286 × 10^6	40.7 × 10^6
Salt load	metric tons	586 000	262 000
Concentration	mg/l	2 170	6 375

* (S_m-S_p) is the net effect of mineral weathering or dissolution (S_m) and salt precipitation (S_p) on the salt load of the drainage water relative to that of the irrigation water ($V_{iw}C_{iw}$).
** V_{iw} and V_{dw} are volume of infiltrated irrigation and subsurface drainage water, respectively.

ing water. The effects of reduced leaching on degradation will be separately discussed for river- and groundwater systems.

River systems

For evaluating the likelihood of reducing river degradation with reduced leaching, river systems may be conveniently classified into two groups.

(1) Rivers whose drainage return "picks up" highly soluble salts from the soil substrata through which the drainage water flows enroute to the river or where the drainage return mixes with a saline groundwater (which is more saline than the drainage water) or displaces it into the river belong to one group. For such situations, reduced leaching will always reduce degradation of the receiving river.

An example is the Colorado River through Grand Valley (many other upper Colorado River basin projects are similar). Here, reduced leaching should reduce the salt load in the river by reducing "pick-up" during drainage and displacement of the highly saline groundwater out of the cobble aquifer, as illustrated in Table IV. The assumed conditions are: consumptive use (cu) of diverted river water in the project is 185 × 10^6 m^3, upstream flow of the Colorado River is 987 × 10^7 m^3, all water applied in excess of cu enters the cobble aquifer displacing an equivalent volume into the river (206 × 10^5 m^3 and 123 × 10^6 m^3 with low and high leaching, respectively). The salinity of the river is increased 13% (56 mg/l) and its salt load 541 000 metric tons with high leaching. While actual conditions are far more complex than those simulated, reduced leaching in the Grand Junction Project should reduce the

TABLE IV

Effect of reduced leaching on river salinity where highly saline aquifer water of independent and constant salt composition is displaced into the river with low and high leaching, simulating Grand Valley, Colorado conditions

Water	Compositions of waters (meq/l)						
	Ca	Mg	Na	K	Cl	Alkalinity	SO_4
Colo. R. upstream*	2.59	0.96	2.49	0.06	1.91	2.31	1.88
Ground-water**	23.1	42.8	30.0	0.41	15.6	10.7	70.3
Colo. R. downstream (low leaching)	2.63	1.05	2.55	0.06	1.94	2.33	2.03
Colo. R. downstream (high leaching)	2.79	1.49	2.84	0.06	2.08	2.35	2.75

* Upstream of irrigation diversion point.
** In aquifer hydraulically connected to Colorado River.

salinity degradation of the Colorado River downstream from this Project.

(2) The second group consists of rivers where no salts enter other than those derived from the water diverted from the river for irrigation and those derived from the weathering and dissolution of minerals (excluding gypsum) in the rootzone. In this case the composition of the drainage water is the same as that leaving the rootzone. Whether river salinity can benefit from reduced leaching depends on the composition of the river water before diversion; the amount of any benefit depends on the extent to which the river is consumed for crop use. Suarez and Rhoades (1977) demonstrated this for hypothetical closed river systems where all drainage was returned. Results from this evaluation at steady state are given in Tables V and VI. Chemical compositions of three common water types are given in Table V. In Table VI the total salinities (expressed in meq/l) and sodicities of the three river types are given at successive downstream locations where drainage from a series of irrigation projects has been returned for situations of low (0.1) and high (0.4) leaching fractions. Regardless of LF, salinity and sodicity are predicted to increase downstream just as they do in all natural rivers (Rhoades and Bernstein, 1971). At equivalent locations downstream, the salinities of the Type 1 (initially undersaturated with $CaCO_3$) and Type 3 (initially saturated with $CaCO_3$ and nearing saturation with gypsum) rivers are lower with low leaching management. The benefit is slight for the Type 1 river and appreciable for the Type 3 river. Reduced leaching increases the sodicities of these rivers only negligibly. The composition of the Type 2 river

TABLE V

Chemical compositions of three common water types before use for irrigation (meq/l)

Water type	Ca	Mg	Na	Sum of cations	Cl	Alkalinity	SO_4
1	0.45	0.36	0.25	1.06	0.04	0.86	0.16
2	2.18	0.60	1.05	3.83	0.21	2.31	1.31
3	8.48	1.56	1.52	11.56	1.05	2.08	8.43

TABLE VI

Salinities and sodicities of rivers of the three common types at various locations downstream after receiving drainage from low and high leaching*

Location below diversion number	Relative percent consumption of river	Water type					
		1		2		3	
		Low	High	Low	High	Low	High
		Salinity (meq/l)					
2	20	1.32	2.07	4.34	4.34	12.4	13.5
5	50	1.95	2.98	5.58	5.58	15.6	20.4
7	70	2.90	3.53	7.77	7.77	20.6	29.3
9	90	6.83	6.83	18.6	18.6	42.9	55.2
		*Sodicity***					
2	20	0.44	0.33	1.07	1.07	0.83	0.79
5	50	0.57	0.44	1.60	1.60	1.21	1.03
7	70	0.79	0.69	2.41	2.41	1.82	1.46
9	90	1.63	1.63	5.24	5.24	4.08	3.40

* After Suarez and Rhoades (1977); types are: (1): unsaturated with $CaCO_3$; (2) saturated with $CaCO_3$, and (3): saturated with $CaCO_3$ and nearing saturation with gypsum.
** Expressed as sodium adsorption ratio, $SAR = Na/\sqrt{(Ca+Mg)/2}$, where solutes are in meq/l.

(initially saturated with $CaCO_3$) is unchanged by leaching differences. Rivers undersaturated with $CaCO_3$ precipitated $CaCO_3$ under low leaching and dissolved $CaCO_3$ under high leaching. Rivers saturated with $CaCO_3$ lost $CaCO_3$ by precipitation in the soil rootzone under low leaching and by precipitation in the river after remixing the drainage water with the undiverted river water under high leaching. During the remixing, the relatively high CO_2 content of the drainage water is lowered upon exposure to atmospheric CO_2

conditions, which decreases the amount of $CaCO_3$ that can be held in solution. The total amounts of precipitation and the compositions were unaffected by leaching differences for this water type. Rivers saturated with $CaCO_3$ and nearing saturation with gypsum lost substantially more salts by precipitation under low leaching than under high leaching.

For the simplified case under discussion, the key to whether river salinity can be reduced with reduced leaching is whether it can accomodate more Ca, HCO_3, or SO_4 in solution as it becomes concentrated. If a river is saturated with these salt constituents, low leaching will have no effect. The additional discharged Ca, HCO_3 and SO_4 salts are precipitated upon the mixing of the return flow with the undiverted river water and the "equilibrated" compositions of the river are the same irrespective of leaching management. If the river water is unsaturated, then the relatively greater salt load ($V_{dw}C_{dw}$) with high leaching will increase its concentration relative to low leaching.

The lower Colorado River is similar to the Type 2 water. Hence, if no salts enter this river after its diversion other than those derived from the diverted water and dissolution of $CaCO_3$ and calcium silicate minerals in the soil during irrigation, its composition in this section should be unaffected by leaching differences. The Palo Verde Project may possibly fit this condition. However, if gypsum were present in the subsurface flow paths of the drainage waters in such projects, then reduced leaching would reduce the salinity of the Colorado River. The same would be true if a more saline groundwater (compared to the drainage water), derived from another source, still underlies the project.

Groundwater systems

As with surface waters, reduced leaching may or may not reduce degradation of groundwaters receiving irrigation drainage. Although a whole spectrum of hydrologic situations may exist, we illustrate only enough for our purpose — to demonstrate the variable benefits and limitations of reduced leaching on groundwater pollution.

Consider the case where substantial aquifer flow occurs from outside recharge and water is pumped from this aquifer for irrigation and its drainage returns to it. For such a case the benefits and limitations of reduced leaching are analogous to the river situations. Whether benefits occur depends on the degree of saturation of the aquifer water with $CaCO_3$ and gypsum.

In the absence of recharge sources other than from drainage return, the groundwater must eventually reach the salinity concentration of the drainage water, which will be higher with low leaching. Before this, however, the groundwater salinity may be lower with reduced leaching for an interim period. This will be illustrated for three different situations.

The first case is one where groundwater is pumped for irrigation with no other recharge source — a case of overdrafting. Groundwater composition of Type 2 or Type 3 is assumed (see Table V). The other assumed condition is that an initial volume of groundwater of 1.23×10^9 m^3 is being depleted in increments of 123×10^6 m^3 for irrigation of a fixed area of land with low (LF = 0.1) or high (LF = 0.4) leaching. Predicted compositions are given in Table VII. With the Type 2 water, degradation of groundwater did not differ with high or low leaching because the water was already saturated in $CaCO_3$. With the Type 3 water, reduced leaching appreciably reduced groundwater degradation. The groundwaters are higher in salinity and lower in sodicity than the river waters under equivalent consumptions because, with the higher CO_2 in the groundwater, $CaCO_3$ does not precipitate as drainage and groundwater are mixed. Hence, the groundwater retains in solution all of the Ca and HCO_3 added by the drainage water. Eventually, the mixed groundwater will be replaced by drainage water. At that time the salt concentration will, of course, be higher with reduced leaching. In the interim period, reduced leaching may produce less degradation of the receiving groundwater.

A second case is where a fixed volume (247×10^6 m^3) of municipal sewage water is being used to irrigate land overlying a groundwater basin whose volume remains steady at 1.23×10^9 m^3. With low LF (0.1), 247×10^5 m^3

TABLE VII

Salinities and sodicities of the Type 2 and 3 groundwaters at various states of consumption with low and high leaching for conditions of a closed basin being overdrafted for irrigation

Relative percent consumption	Water type			
	2		3	
	Leaching			
	Low	High	Low	High
	Salinity (meq/l)			
20	8.97	8.97	16.9	17.9
50	10.28	10.28	20.1	24.7
70	12.61	12.61	25.3	33.5
90	23.96	23.96	48.1	59.6
	*Sodicity**			
20	0.64	0.64	0.69	0.67
50	0.99	0.99	1.04	0.92
70	1.56	1.56	1.59	1.35
90	3.85	3.85	3.75	3.22

* Expressed as sodium adsorption ratio, $SAR = Na/\sqrt{(Ca+Mg)/2}$, where solutes are in meq/l.

of drainage water mixes with the groundwater; with high LF (0.4), 987 × 10^5 m^3 of drainage water mixes with the groundwater. The areas irrigated differ in the two cases. A volume of groundwater equivalent to the drainage volume is assumed displaced from the basin before mixing occurs. The same process is continued each year. The compositions of the irrigation and drainage waters, and the predicted groundwater compositions after 10 years are given in Table VIII. High leaching resulted in less saline groundwater than did low leaching, primarily because less land can be irrigated with a fixed volume of water with high leaching; and hence, consumptive use is less. It is, however, possible for low leaching to produce lower salinity groundwater during early stages of such mixing. This possibility, not intuitively obvious, may be seen by considering the groundwater composition after the first mixing cycle. Where C_{gw} and C'_{gw} are the original and final salt concentrations of the groundwater body of fixed volume, V_{gw}, V_{dw} and C_{dw} are volume and concentration of drainage water respectively, and $(V_{gw} - V_{dw})$ is the fraction of the groundwater not displaced from the basin by drainage inflow which remains to mix with drainage,

$$C'_{gw} = [V_{dw}C_{dw} + (V_{gw} - V_{dw})\, C_{gw}]/V_{gw}. \tag{2}$$

With low leaching, $(V_{dw}C_{dw})$ is less and $(V_{gw}\text{-}V_{dw})$ is more than with high leaching. Thus, whether or not low leaching degrades the groundwater less at this time of first mixing depends on C_{gw}. If C_{gw} is sufficiently low, low leaching may at first produce less degradation. This may be seen in Eq. (3)

$$\Delta(C'_{gw})_{H\text{-}L} = \{ [(V_{dw}C_{dw})_H - (V_{dw}C_{dw})_L] - [(V_{dw})_H - (V_{dw})_L]\, C_{gw} \} / V_{gw}, \tag{3}$$

where H and L refer to high and low leaching, respectively. If $[(V_{dw})_H - (V_{dw})_L]\, C_{gw}$ is less than $[(V_{dw}C_{dw})_H - (V_{dw}C_{dw})_L]$, $\Delta(C'_{gw})_{H\text{-}L}$ will be positive, which means that high leaching will increase salinity relative to low leaching. This can happen when C_{gw} and $(V_{dw}C_{dw})_L$ are very low. Hence, with the first additions of drainage to a dilute groundwater, low leaching may increase groundwater salinity less than high leaching, but with continued usage C_{gw} will increase and low leaching will cause more degradation. Finally, the groundwater will come to the concentration of the drainage water, which is highest under low leaching.

Even if the groundwater volume were not fixed, but allowed to be recharged differentially with low and high leaching, the results would be the same. The rate of salinization, however, would be lower than for the fixed groundwater volume.

Finally, consider the situation where saline water is imported for irrigation of a fixed area. We assume an initial groundwater basin of 1.23 × 10^9 m^3 and an annual consumptive use of 123 × 10^6 m^3. Then, different volumes of irrigation water, 137 × 10^6 m^3 and 206 × 10^6 m^3 for low and high leaching, respectively, are imported and applied to the land. The corresponding drainage volumes are 137×10^5 m^3 and 822×10^5 m^3. The composition of the irrigation water and original groundwater are the same as before. The salinities of the groundwater at the end of each year are given in Table IX. This salinity is lower with low leaching for the first 12 years of irrigation. However, for all years thereafter, groundwater salinity is lower with high leaching. The groundwater salinities will eventually approach those of the drainage waters, 108 and 33 meq/l for low and high leaching respectively.

These computations are based on the assumption that the rootzone and aquifer have the same CO_2 concentration (3% CO_2). If CO_2 level differed, different groundwater salt concentrations would result and $CaCO_3$ could precipitate in the aquifer upon mixing of the drainage water. The buffering capacities of rootzone and aquifer matrices could also affect the resultant concentrations for some time, as could the slow travel time to the ground-

TABLE VIII

Compositions of irrigation, drainage and original groundwater and groundwaters after 10 years of receiving irrigation drainage from low and high leaching*

Water	Compositions of waters (meq/l)					
	Ca	Mg	Na	Cl	Alkalinity	SO_4
Irrigation water	5.2	2.5	5.5	3.2	2.5	7.3
Drainage from low leaching	28.5	24.7	54.8	31.8	7.1	69.1
Drainage from high leaching	13.3	6.2	13.7	7.9	7.1	18.1
Original ground-water	6.4	1.1	1.0	0.3	7.2	1.1
New ground-water with low leaching	10.7	5.4	10.9	6.1	7.4	13.5
New ground-water with high leaching	10.3	4.0	8.2	4.6	7.2	10.7

* The irrigation water is similar to that expected from domestically used Colorado river subsequently reused for irrigation; the groundwater is similar to that in the upper Santa Anna basin at Colton.

TABLE IX

Salinities of groundwaters after increments of drainage from low and high leaching irrigation with imported water*

Years of irrigation	Groundwater salinities (meq/l)	
	Low leaching	High leaching
2	10.9	11.8
4	13.1	14.6
6	15.2	17.0
8	17.3	19.1
10	19.3	20.9
12	21.2	22.5
14	24.1	23.8
16	25.9	25.0
18	27.7	26.1
20	29.5	27.0

* The drainage water is similar to that expected from domestically used Colorado river subsequently used for irrigation; groundwater is similar to that in the upper Santa Anna basin near Colton. These compositions are given in Table VIII.

water. In the preceding calculations, the aquifer was assumed to be a sand with negligible cation exchange capacity. Hence the magnitudes of the groundwater concentrations should not be taken as absolute. The conclusions about the direction of the effects of LF on salinity and sodicity are valid.

OTHER CONSIDERATIONS RELATED TO EFFECTS OF MINIMIZED LEACHING

Increased soil salinity and sodicity

Although low leaching always reduces the salt load of drainage waters and sometimes the salinity of the receiving water, it always increases the salinity and sodicity of the soil and drainage waters. Representative total concentration and SAR values are given in Table X for quarter depths of a soil rootzone irrigated with the Type 2 water at LF 0.1 and 0.4. The salinity and sodicity of the soil will also increase as the salinity and sodicity of the irrigation water increase. Some crops can tolerate high levels of salinity and sodicity without yield reduction and some cannot (Bernstein, 1964). In any case, reduced leaching with any water will cause substantial differences in salinity and sodicity only in the lower half of the rootzone. Thus, how much the LF can be reduced is limited by the tolerances of the crops being grown to the increased deep rootzone salinity. Based on current evaluations of plant response to

TABLE X

Salinities and sodicities of soil water by depth in rootzone with use of the Type 2 water for low (LF = 0.1) and high (LF = 0.4) leaching

Quarter depth of rootzone	Salinity (meq/l)		SAR*	
	Leaching		Leaching	
	Low	High	Low	High
1	9.0	8.2	1.9	1.7
2	14.6	11.3	2.7	1.9
3	24.1	13.7	4.3	2.1
4	40.6	15.5	6.8	2.3

* SAR = $Na/\sqrt{(Ca + Mg)/2}$, where solute concentrations are in meq/l.

nonuniform rootzone salinity, leaching requirements for crops are substantially lower than current leaching practices (Bernstein and Francois, 1973; Rhoades, 1974; Ingvalson et al., 1976). In most irrigation projects, current LF levels could be reduced appreciably without crop yield reductions, especially with commensurate improvements in irrigation management.

The effects of the increased levels of SAR and chloride in the lower rootzone are not well understood, but no problems are expected with the anticipated levels. Neither would reduced permeabilities be expected with reduced leaching because of the offsetting effect of increased electrolyte level accompanying the increase in SAR (McNeal and Coleman, 1966; Rhoades, 1968).

Loss of soil porosity by salt deposition

Salt is deposited in the soil even with high leaching because $CaCO_3$ is dissolved in the upper rootzone (because soil air is richer in CO_2 than the atmosphere) and is redeposited in the lower rootzone (where the water becomes more concentrated), even though there is no net deposition of $CaCO_3$ in the soil from the irrigation water.

As shown in Table II, decreasing LF enhances precipitation of $CaCO_3$ and gypsum in the soil. Both of these minerals are common soil amendments and do not decrease plant growth. There is some concern, however, about loss of soil permeability resulting from the increased deposition of these minerals within the soil pores with reduced leaching.

Suarez and Rhoades (1977) evaluated the change in soil profile porosity that would be expected with reduced leaching, using the three water types discussed earlier. For $CaCO_3$-saturated waters (Type 2), a change from high to low leaching resulted in a maximum porosity reduction within any quarter depth zone of 0.008% more per year. For waters that result in the precipitation of gypsum (Type 3), porosity was reduced about 0.08% more per year within the quarter depth zone of greatest deposition with low leaching. Calcium carbonate deposition was maximum in the second soil rootzone quarter, decreasing below. For the Type 2 water, calcium carbonate deposition was approximately in the ratio 2 : 1.5 : 1 for the second, third and fourth soil intervals, respectively. For the Type 3 water, the corresponding ratio was approximately 2.7 : 1.8 : 1. Loss of soil porosity from salt deposition should not be detrimental unless the salts deposit in a narrow band. The salts should deposit where they are concentrated during water uptake, near the root hairs, which are distributed throughout the soil mass. Thus, deposition should be diffuse and should differ from year to year, and plugged strata or pans would not be expected. Furthermore, the deposited salts are particulate so that with discing or plowing they would be similar to other constituents of the soil matrix.

Miscellaneous considerations

Reducing the LF in irrigation will reduce the diversion and drainage requirements, and thus the distribution and collection systems. The reduced drainage volume should minimize drainage problems with their associated adverse effects of poor aeration and waterlogging. It will also lessen nutrient loss and, hence, fertilizer requirements (Branson et al., 1975).

Achieving a lower leaching rate may often require more automated and sophisticated irrigation systems and management techniques. The hazard of reduced yield would be increased in instances of accidental water stress because of the smaller amount of low-salinity water within the rootzone.

CONCLUSIONS

Minimized leaching may or may not reduce salinity degradation relative to high leaching. Each situation must be evaluated relative to its specific conditions.

Salt discharge from irrigated lands will always be reduced with reduced leaching. Where drainage waters can be prevented from returning to receiving waters, degradation will be avoided. The amount of salt and volume of drainage water to be disposed of or desalted will always be reduced with minimized leaching. Thus, where desalting is feasible, minimized leaching will be beneficial.

Where the drainage water is returned to a surface water, a reduction in leaching may or may not reduce the salt concentration of the receiving water. Such reduction will generally occur where saline groundwaters with concentrations in excess of those of the recharging drainage waters are displaced into the surface water. Many such situations occur in the Upper Colorado River Basin. Reduced leaching will also reduce the salinity of receiving surface waters if the latter are undersaturated with $CaCO_3$ and/or gypsum and the drainage water becomes saturated with one or both of these minerals. Reduced leaching will not reduce receiving water salinity if the receiving water is already saturated with these constituents. Considerable benefits from reduced leaching on river salinity pollution will occur with "gypsum-type" waters similar to the Pecos and Lower Rio Grande which are undersaturated with gypsum but relatively high in Ca and SO_4 and which deposit gypsum in the soil. Similar benefits will result where low salinity waters are used to irrigate gypsum-containing soils or soils with underlying gypsum-containing substrata. Rivers unsaturated with gypsum but essentially saturated with $CaCO_3$ will not benefit from reduced leaching unless salts other than that from the diverted water and soil mineral weathering and dissolution are encountered in drainage flow paths or a "foreign" saline groundwater is displaced by drainage flow to the river. The Colorado River in its lower basin is probably of this type.

Like surface waters, groundwater receiving irrigation drainage water may or may not benefit from reduced leaching. With no sources of recharge other than drainage return flow, the groundwater eventually must come to the composition of the drainage water, which will be more saline with low leaching. Before this, however, the groundwater salinity may be lower with reduced leaching for a period of time. For groundwater being pumped for irrigation with no recharge other than by drainage return, the short-term limitations are the same as described previously for the three water types. Groundwater undersaturated with $CaCO_3$ (unlikely in arid lands) will show a slight benefit under low leaching, water saturated with $CaCO_3$ will show no benefit under low leaching, and water saturated with $CaCO_3$ and nearing saturation with gypsum will show substantial benefit from low leaching. If there is sufficient flow into and out of the basin, then the benefits and limitations of reduced leaching on basin salinity are also analogous to the river situations.

Where irrigation water of lower quality than the receiving water is imported into groundwater basins without other recharge sources, some extra recharge will occur with high compared to low leaching. But more salt will be discharged with high leaching because of the increased amount of water, reduced precipitation, and enhanced dissolution of salts. Hence, at first, low leaching will result in lower groundwater salinity. Again, with time, a "cross-over" in concentration will occur. This cross-over can be prevented, i.e., low leaching can continuously reduce degradation of the groundwater, only if other sources of high-quality recharge into the basin exist and if flow out of the basin is adequate relative to drainage inflow. If a fixed volume of saline water is disposed of in a fixed basin by irrigation, groundwater salinity will usually be lower with high leaching, though not always.

The extent to which leaching can be minimized in practice is limited by the tolerances of crops to increased salinity in the lower part of the rootzone. In most irrigation projects, currently used LF's could be reduced appreciably without harming crops or soils, especially with improvements in irrigation management. The expected decrease in soil porosity from salt deposition should not be detrimental.

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