Waterlogging and Salinity in the Indus Plain: Comment

by

FRANK M. EATON*

Not only does Ghulam Mohammad's contribution on waterlogging and salinity in the Indus Plain [5] reflect a wide understanding of the agricultural problems of Pakistan but the clarity of his presentation is commendable. My comments all have to do with water quality and drainage problems in this vast irrigated area with the future rather than the immediately present problems primarily in mind. I trust that all statements will be regarded as constructive rather than critical.

The changes now occurring with irrigation in the compositions of the initially high-quality canal waters of the Indus Plain as these waters become groundwaters, appear to be little different from the past changes which occurred more slowly but which are responsible for the diverse compositions of the present groundwaters. Many of these present-day groundwaters were left behind by the flood waters which deposited the valley alluvium. The flood waters left on the land surface underwent concentration by evapotranspiration with precipitations of CaCO_3 and losses of Mg in the form of compounds of salica. As a result of these precipitations there were increases in the proportions of Na.

That little of the salt being left in the soils and groundwaters of Pakistan with irrigation is now being carried to the sea is indicated by the finding that a sample of the Indus River collected near Karachi in February 1953, when the discharge was very low, was only a little more saline than that of waters sampled near the upper head works [3]. The Karachi sample was reported to have been about 80 per cent return flow from surface runoff and drainage from irrigated lands.

The fact that little of the salt brought onto the lands of the Indus Plain by the rivers and canals is being discharged into the sea, represents a major long-time threat to the permanency of the agriculture of West Pakistan unless a suitable means of disposing of the salt residues of these irrigation waters

*Dr. Frank M. Eaton is the Associate at the Agricultural Experiment Station, University of California, Riverside, California.

is developed. History has repeatedly demonstrated that a permanent agriculture requires that the salts added to irrigated lands be balanced by a commensurate salt removal. The mere fact, however, that a "salt balance" is achieved may be meaningless if the balance exists only after the lands are too saline for a self-supporting agriculture. Drainage facilities should be established before, rather than after, an agriculture is impoverished.

One automatically cringes at the thought of discharging saline drainages into the canals and rivers that are supporting downstream agricultures. The destruction of old agricultures to promote new ones can provide no mental comfort. The longevity of an agriculture which supports many millions of people should be viewed in terms of centuries rather than on the basis of an expedient which may suffice for only a limited number of years.

The *Report on Land and Water Development in the Indus Plain* [8] and the Panel's paper estimate that with recycling of the groundwater to supply additional irrigation water and at the same time prevent a further increase in waterlogging, the groundwaters will, with 10 to 50 years of pumping, have become too saline for further use.

The reports further recognize that the quality of the groundwaters underlying the Indus Plain are uneven: "... pools of poor quality water are interspersed among the good." By the data presented for the Northern Plain, only one-third of the groundwater contains less than 500 ppm of total salt. A total of 38 per cent contains more than 1000 ppm of salt. The reports recognize that a disastrous infiltration of bad waters into the good will occur if the elevations of the good waters are reduced by pumping below the elevations of the bad. In other words, the idea is accepted that both the bad and good waters must be simultaneously pumped but the statement on how the bad waters should be disposed of is not very specific. It is suggested only that the bad waters might be discharged into lagoons or returned to the rivers during flood periods.

Two questions are raised by these proposals, particularly since the areas of bad waters will progressively expand during the 10 to 50 year periods of pumping until all waters are salinized. When the good waters are exhausted, Pakistan will again be dependent on canal waters. Neither the present nor future bad waters which require pumping will necessarily be adjacent to the rivers. The canals for distributing irrigation waters were designed for distribution only and it would appear to require much planning and construction of new drainage works to carry away the discharges of widely scattered wells pumped only to protect the quality of the pools having good water. The problem of disposing of the saline groundwaters is recognized as one which will become

progressively more acute as pumping is continued. Eventually, there will be only limited sources of good groundwaters which can be pumped and the disappearance of good waters will become more rapid if the bad waters are not pumped.

It seems important that decisions should be made now, rather than later, as to: *i*) who will pay for pumping the bad waters and, *ii*) how will they be disposed of?

Without pumping, the levels of all groundwaters will continue to rise into root zones in the future as they have risen in the past. Waterlogging of once fertile lands has been progressive in the past in Pakistan. Without a drainage system which is designed with the same care that the distributary system was designed, the problem of land abandonment will become more acute. As lands are abandoned because of waterlogging and salinity, it is reasonable to believe that farmers will be no more able to pay for drainage systems in the future than they are at present or have been in the past.

The two reports which have been cited emphasize advantages of the vertical (pumping) drainage systems over horizontal systems. They point further to the difficult and high costs of integrating a drainage system with the distributary system. It may be true that it would be less costly to dispose of the saline drainages by pumps discharging into special canals than by a horizontal system but, if so, only with the provision that the government, or some other agency, would provide and operate the pumps and dig the canals that would dispose of the bad waters. When pumps no longer yield good waters, the agriculture of Pakistan will be in the same position that it was in before the present pumping episode was started.

Water Quality

The water quality statistics, employed by the Panel in its initial report and in response to the articles by Ghulam Mohammad, rely on salt concentrations expressed as parts per million of total salt. There is no summary of the percentages of high-sodium, high-bicarbonate groundwaters, or of the concentrations of calcium and magnesium relative to the concentrations of carbonates and bicarbonates. With values for these components in the groundwaters, it is possible to estimate the alkalinity hazards and the effects of the waters on soil permeability. From water analyses based on the concentrations of individual ions, it is possible to estimate the percentage of the applied water which must be passed through and out of the bottom of the root zone to carry salts away fast enough to permit yields 80 per cent as high as those possible on non-saline lands. Also, with these values it is possible to estimate

the amount of gypsum which should be applied to the water or to the land to prevent high alkalinity, serious soil impermeability, and the deficiencies of the calcium and magnesium required for normal growth. Knowledge of the existence of the alkali problem, both present and future, is indicated by the inclusion, in the paper by Dorfman, Revelle, and Thomas, of a discussion of the "sodium hazards". There were no statistics to indicate the magnitude of the problem represented by the composition of the groundwaters or of the proportion of the land which is now so high in sodium that leaching is too slow to be fully effective. No mention is made of the use of gypsum as a corrective.

On the basis of the old groundwater analyses, which the writer was able to find in Pakistan at the time of his three-month visit in 1952-1953, the problem of excess sodium and high alkalinity in soils and groundwaters impressed him as being serious and deserving of careful attention. Since that visit, Hausenbuiller, *et al* [6, pp. 356-364] were similarly impressed and recommended applications of gypsum where needed. The writer recalls experimental data from the vicinity of Montgomery which demonstrated outstanding yield benefits from the use of gypsum. No practical substitute for the use of gypsum on high sodium alkali lands is known.

Ghulam Mohammad has reviewed [5, pp. 357-403], the now-available analyses of groundwaters of the Indus Plain. Even on the questionable assumption that 1.25 me./l of residual sodium carbonate may be safe (*see*, later discussion), the data show that the ^{most} saline waters are commonly so high in sodium and/or bicarbonate as to make their use hazardous unless they are mixed with canal water or treated with gypsum.

Private interests will undoubtedly avail themselves of the groundwaters of Pakistan by pumping only so long as the qualities of these waters permit profitable crops. When there is no longer a profit, the wells will be abandoned, after which the watertables will again rise. It seems doubtful at this stage that private funds will be available for the construction of the drainage system which should have been established when the distributary canals were constructed. The cost of a country-wide drainage system is so great that it seems doubtful that public agencies can now undertake it.

On-Farm Drainage

It was for the foregoing reason, and the foregoing reason only, that the writer in his FAO report [3] suggested a type of drainage system which he believed the farmers themselves could install and maintain. Such a system, although not ideal, may be the only recourse possible, now or in future, in many areas of Pakistan.

Under ideal practice, saline drainages should discharge into the sea or into natural closed lakes or large land depressions. Horizontal drainage systems of large scale are expensive and, as noted in the reports cited, they seriously interfere with water-distributary systems.

The lands of Pakistan tend to be flat and for that reason, the drainage canals would have to be of large capacity and often augmented by pumping to obtain the necessary discharges. Also to accommodate the necessary depths of field drains, the public canals would have to be deep.

As has been repeatedly noted by others, Pakistan has a great surplus of arable land in relation to its water supply. It is now apparent that the distributary system was designed to serve more land than could be cropped at any one time. It seems possible, if not probable, that the planners hoped thereby to at least slow down the rate of rise of the watertables, and thereby to postpone waterlogging. Over vast areas waterlogging has now become acute.

With the great excess of arable land, the writer believes that the cultivated acreages could appropriately be cut back to approach the land that can be served by canal or good-quality groundwaters. With such cut backs, there will be continuously idle lands that can be converted to evaporation flats—areas which are surrounded by low dikes or areas upon which the saline drainages can be spread by networks of furrows.

In the light of the effects of canal seepage and rainfall on rising watertables, in addition to the necessary leaching to remove existing salinity and to continuously remove the salts deposited in soils with irrigation, it is possible to estimate the required areas of the on-farm evaporation flats in relation to the area of the land irrigated. With knowledge of evaporation rates, leaching requirements, rainfall, and surface runoffs, such estimates become quite simple.

Under the evaporation-flat system, the farmer himself would install the field drains (tiles or ditches) and the disposal ditches leading to his evaporation flat. Since the field and connecting drains should be installed to depths of upward to seven feet or more, small on-farm deep collecting sumps are necessary for the accumulation of the day-to-day drainage. Pumps, whether power or Persian wheel, are necessary for the discharge of drainage effluents from the sumps onto the evaporation flats.

The installation of on-farm evaporation flats is, of course, not an ideal substitute for country-wide drainage systems. But the method, as an alternative, is regarded by the writer as one of much promise under the existing

circumstances and one which would permanently reverse the downward trend in production which has resulted from waterlogging and salinity.

Deep field and collecting drains should always serve the double purpose of disposing of saline wastes and of providing deep, well-aerated root zones.

Water Quality Evaluation

If a water is to be used for irrigation, it is deserving of a careful chemical analysis to make possible estimates of how it can be used most effectively. From analyses for each ion expressed in milligram equivalents per liter (me./l), it is a simple matter to calculate leaching, or drainage, requirements and to estimate, also, the amount of gypsum which should be applied to maintain permeability and high production.

Ghulam Mohammad has pointed to a weakness in the Revelle Report in that emphasis was placed on total salinity with a neglect of the significance of bicarbonate in the precipitation of calcium and the resulting higher sodium percentages. He regards it as probable that many groundwaters which the Panel recommended as suitable for irrigation would result in low soil permeability and high alkalinity unless mixed with large quantities of canal water or used with heavy applications of gypsum. Because of insufficient canal water, the necessity of gypsum, and the costs of development, he recommends the elimination of tubewell installations over the Punjab and Bahawalpur, and undoubtedly elsewhere, except where sodium and bicarbonate concentrations are found to be low relative to calcium and magnesium. On the other hand, many waters that are now unsuitable for irrigation because of high bicarbonate can be successfully used by additions of gypsum. Reference will be made in a subsequent paragraph to the nature of the experimental evidence which led the Panel to regard 1.25 me./l of residual sodium carbonate in irrigation waters as "probably safe". Workable gypsum deposits are available in Pakistan and experimental evidence exists in Pakistan which shows that notable benefits of gypsum applications have resulted even in some of the canal-irrigated land. Hausenbuiller, *et al* [6, pp. 357-364] note that while power and machinery for mixing gypsum with water may be expensive, applications of the finely powdered material directly to the land is practical.

Ghulam Mohammad refers to statements by Hanson, Bower and Williams on advantages of maintaining subsurface waters within the lower root zone if care is taken to insure that adequate salinity control is exercised. Although it is true that water may be effectively stored in the deeper root zone, as in the polders of Holland where salinity is not usually a problem, the dangers of extending the concept to some of the irrigated lands of Pakistan are obvious.

If an irrigation water containing 10 units of chloride is used over a few years to produce a uniform 10 per cent of leaching, the leachate will contain 100 units of chloride; with 20 per cent of leaching, the leachate will contain 50 units of chloride; but with only 1 per cent of leaching there eventually will be 1000 units of chloride in the drainage. Drainage systems serve the double purpose of increasing the depth of aerated soil and of removing salt from the land. Plants take up more salt—relative to water uptake—as concentrations are increased and it is the salt in the plant that depresses growth.

Prior to my short visit to Pakistan in late 1952 and early 1953, I had spent a good bit of time developing a set of simple equations for evaluating the quality of irrigation waters in the light of field and experimental responses. Those equations were included in my FAO report to Pakistan [3] and later published with the background information as *Texas Agricultural Experiment Station Miscellaneous Bulletin 111, 1954*. Since then a few minor simplifications and changes in constants have appeared to be advantageous.

Inasmuch as CaSO_4 added to a soil or water increases the SO_4 content, one first computes the Ca requirement of the water and then adds $\frac{1}{2}$ the required Ca to the sum of $\text{Cl} + \frac{1}{2}\text{SO}_4$. For a number of plants, SO_4 has proven to be only half as toxic as Cl, equivalent for equivalent.

Calcium and Gypsum Requirements

The object here is to produce leachates with no more than 70 per cent Na.

Required Ca: me./l = sum of a, b, and c as shown below:

a) Ca + Mg needed, if any, so that the Na per cent will not exceed 70:

$$\text{Na} \times 0.43 - (\text{Ca} + \text{Mg}) \quad \text{Retain + or - sign}$$

b) Compensate for $\text{CaM} + \text{g}$ that will probably be precipitated:

$$(\text{CO}_3 + \text{HCO}_3) \times 0.7$$

c) Compensate for the Ca + Mg in excess of Na that is removed from the land by average crops: Add 0.5 me./l. This value is suggested for Pakistan because of the large amounts of forage which is carried into the villages. Without such removals the value 0.3 me./l is suitable.

Gypsum Equivalent of required Ca:

sum of a, b, and c $\times 234$ = pounds of gypsum, if any, per acre foot of water. (See, guide in Table I).

Leaching Requirements

RL = Leaching requirement

Sw = Salinity of the water expressed as $\text{Cl} + \frac{1}{2}\text{SO}_4 + \frac{1}{2}$ required Ca.

Mss = Mean soil solution concentration expressed as: $\text{Cl} + \frac{1}{2}\text{SO}_4$ i.e., the average of the water and leachate.

TABLE

GUIDE FOR COMPUTING THE LEACHING AND

Water No.**	EC × (10) ⁶	Composition of water me./liter							Calculations (see	
									Calcium	
									(a) Na × 0.43 Minus (Ca + Mg)	(b) CO ₃ + HCO ₃ × 0.7
		Ca	Mg	Na	CO ₃	HCO ₃	SO ₄	Cl		
1	52	0.21	0.12	0.19	0.00	0.34	0.05	0.16	-0.25	0.24
2	350	1.15	0.93	1.78	0.00	1.14	0.67	1.72	-1.315	0.798
3	420	2.35	0.75	1.39	0.00	2.94	0.98	0.56	-2.503	2.058
4	985	4.17	2.26	3.81	0.00	2.76	5.51	2.11	-4.80	1.93
5	789	0.24	0.02	7.28	0.00	2.39	2.48	2.47	2.87	1.67
6	2170	2.33	0.57	17.43	0.00	1.92	6.30	11.92	4.59	1.34

**Water sources: (1) San Joaquin River, California, (2) Gage Canal, Riverside, California, (3) California, (6) Well, Coachella Valley, California

*A mean soil solution (Mss) value of 30 is used for this calculation.

†This is the per cent of irrigation water applied which must be passed beyond the root zone to

I

GYPSUM REQUIREMENTS OF IRRIGATION WATERS

formulas under text (pages 387-391)					Appraisal	
Requirement		Leaching requirement			Gypsum requirement (d) × 234 = lbs. Gyp./ac. ft. water	Leaching require- ment in per cent†
(c) Crop removal adjustment	(d) Ca Require- ment in me./l. [(a) + (b) + (c)]	Sw = Cl + $\frac{1}{2}$ SO ₄ + $\frac{1}{2}$ required calcium	2 × Mss* — Sw	LR = $\frac{Sw \times 100}{2 \times Mss - Sw}$ (per cent)		
0.30	0.29	0.33	59.67	0.5	68.0	0.5
0.30	—0.21 (None)	2.10	57.90	3.6	None	3.6
0.30	—0.14 (None)	1.05	58.95	1.8	None	1.8
0.30	—2.57 (None)	4.86	55.14	8.8	None	8.8
0.30	4.84	6.13	53.87	11.4	1130.0	11.4
0.30	6.23	18.18	41.82	43.5	1460.0	43.5

Tracy Mendota Canal, California, (4) Colorado River, U.S.G.S. 1950, (5) Wel, Bakersfield,

keep salt from accumulating beyond levels consistent with good crop performance.

$$RL = \frac{Sw \times 100}{2 \times Mss - Sw}$$

For annual plants of low salt tolerance ... $Mss = 20$

For annual plants of medium salt tolerance ... $Mss = 30$

For annual plants of high salt tolerance ... $Mss = 75$

For standard water-quality comparisons, the use of $Mss = 30$ is suggested.

Comments on the Derivation of the Equations

The leaching requirement, RL, represents the percentage of the applied irrigation water which should be passed through and out of the root zone as leachate for the maintenance of yields averaging 80 per cent as high as on similar non-saline soil. If the equations, when converted to acre inches of leachate, for example, show that there should be five acre inches of leachate, this amount remains valid irrespective of whether the actual leaching is brought about by irrigation or by rainfall, *i.e.*, the rainfall may produce the leaching but the acre inches of required leachate computed on the basis of the amount of irrigation water applied is not changed.

In the RL calculation, unreasonably high values result if either the electrical conductivity or sum-of-cations is substituted for $Cl + \frac{1}{2}SO_4$, because HCO_3 would be included; HCO_3 is not significantly accumulated by plants. But its presence as $NaHCO_3$ depresses Ca and Mg accumulations. These ions, in ample amounts, are essential for good crop production. It is more economical to avoid the adverse effects of HCO_3 by the use of gypsum than by extra leaching. In the instance of the Indus River at Sukkar on January 30, 1953 [3], the leaching requirement by the present equations is 1.4 per cent. But on the basis of electrical conductance or sum of anions or cations, the requirement is found to be several times greater and unreasonably high.

The expression, in the Ca requirement equations, $Na \times 0.43$ shows the amount of Ca + Mg needed for 70 per cent Na. If a water contains 5 me./l of Na then $Na \times 0.43$ shows that 2.15 me./l of Ca + Mg will be needed to give 70 per cent Na. The deficiency or excess from 2.15 is carried forward with the plus or minus sign in computing the Ca requirement: $a + b + c$.

The present Mss values (used in the denominator of the RL equation), are lower than those previously suggested because of experimental results [4, pp. 411-416] showing that chloride accumulates at root surfaces and gives rise to higher accumulations in plants on a soil than on a water culture even though the substrate concentrations are maintained at the same level.

The extent of precipitation of CaCO_3 in soils is a function of the CO_2 partial pressure in the soil atmosphere and the concentrations of the reacting constituents. The latter are largely determined by leaching rates but estimates of CO_2 partial pressures in soils are difficult since they are dependent on the density in the soil of living and dead roots, their respiratory rates, and the freedom of gaseous exchange between the soil and the air above. The pH of soils measured in the laboratory after exposure to the atmosphere are usually much higher than when measured in place in the field.

Only a few good data are available on the proportion of the HCO_3 in water supplies that are normally precipitated in soils. Among the best of these are the results presented by Pratt, *et al.* [7, pp. 185-192]. It was found that in the order of 50 per cent of all the HCO_3 applied by an irrigation water with "88 per cent sodium possible" (*i.e.*, Ca — 2.43, Mg — 0.76, Na — 1.46, and HCO_3 — 3.00 me./l) was precipitated both in a 20-year lysimeter experiment and in an orchard irrigated for 38 years. In the foregoing "Ca requirement" equations use is made of Pratt's average value for loss of HCO_3 , *i.e.*, 50 per cent, but in addition a 20 per cent allowance is made for the precipitation of Mg largely in the form of silica compounds, *i.e.*, the value $0.7 \times \text{HCO}_3$ is used in computing Ca + Mg requirements.

It is unfortunate that each of three extended (21 months to 4 years) and carefully conducted experiments on the significance of $\text{CO}_3 \cdot \text{HCO}_3$ in irrigation waters failed to take account of the importance of CO_2 partial pressures in the soil atmosphere on the extent of precipitation of CaCO_3 (Wilcox, *et al*[9, pp. 259-266]); Babcock, *et al*[2, pp.155-164]; and Hausenbuiller, *et al*[6, pp. 357-364]. In each of these experiments the plants—respectively, Rhodes Grass, alfalfa, and Bermuda Grass—were grown in containers and irrigated with waters having various ratios of Ca: Na and HCO_3 : Cl. The oversight in the experimental designs is represented by the fact that the containers were not surrounded by densities of plants equal to those of the test plants in the containers. With the foregoing provision, lateral light would have been reduced and the top growths would have been more nearly proportional to soil area. But with the tops spreading out, the root densities must have been very high in the limited soil volumes (2, 32, and 5 gallons, respectively). The production of respiratory CO_2 being somewhat proportional to root density, the precipitation of CaCO_3 would, to a corresponding extent, have been inhibited by the high CO_2 partial pressure, and the development of high ESP would have also been restricted. Babcock, *et al.* [2] make the observation that while little CaCO_3 precipitation occurred in their soils, it did occur in their collecting pans as the leachates came into equilibrium with the outside air.

Hausenbuiller, *et al* [6] obtained a correlation coefficient of .984 between the residual Na_2CO_3 in 11 waters and the exchange sodium percentages found in the top eight inches of 11 soils and yet five of the waters contained less HCO_3 than $\text{Ca} + \text{Mg}$. In accord with Pratt, *et al.* [7] much CaCO_3 may be precipitated even though there is no residual Na_2CO_3 in the water. Pratt, *et al.* [7] found rather large increases in the ESP and pH values of the irrigated soils in both the lysimeter and field experiments.

REFERENCES

1. Asghar, A.G. and M.A. Hafeez Khan, "Behaviour of Saline-Alkaline Punjab Soil Under Reclamation", *Proceedings of Punjab Engineering Congress*. (Lahore: Punjab Engineering Congress, 1955).
2. Babcock, K.L. *et al.*, "A Study of the Effects of Irrigation Water Composition on Soil Properties", *Hilgardia*, 29(3), 1959, pp. 155-164.
3. Eaton, F.M. *FAO Report No. 167 to the Government of Pakistan on Certain Aspects of Salinity in Irrigated Soils*. (Rome: FAO, September 1953).
4. —————, and J.E. Bernarelin, "Mass Flow and Salt Accumulation by Plants on Water Versus Soil Culture", *Soil Science*, Vol. 97, No. 6, June 1963.
5. Ghulam Mohammad, "Waterlogging and Salinity in the Indus Plain: A Critical Analysis of Some of the Major Conclusions of the Revelle Report", *Pakistan Development Review*, Vol. IV, No. 3, Autumn 1964.
6. Hausenbiller, R.L., M.A. Haque and Abdul Wahab, "Some Effects of Irrigation Waters of Differing Quality on Soil Properties", *Soil Science*, Vol. 90, 1960.
7. Pratt, P.F., R.L. Branson and H.D. Chapman, "Effect of Crop, Fertilizer and Leaching on Carbonate Precipitation and Sodium Accumulation in Soil", *VII International Soil Science Soc. Cong. Trans. 2*, Vol. 11, 1960.
8. White House, Department of Interior Panel on Waterlogging and Salinity in West Pakistan, *Report on Land and Water Development in the Indus Plain*. (Washington D.C.: Suptt. Doc. January 1964).
9. Wilcox, L.V., G.Y. Blair and C.A. Bower, "Effect of bicarbonate on suitability of water for irrigation", *Soil Science*, Vol. 77, 1954.