Sodic Soils in Iraq

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The precursor of a sodic soil, it may be said, is a saline soil. Saline soils were recognized and written about in the country which is today Iraq, as far back in history as 2400 BC. The first location of them according to the records[4] was in connection with wet areas, correlated with irrigation, in northeastern Sumer in the vicinity of modern Telloh. The characteristics ascribed to them identify them as the NaCl variety. Writings about them indicative of an increasing prevalence of them persisted to about 1700 BC when the last remnant of Sumerian civilization disappeared from history. The next writings about them located them in Babylonia about 1200 BC. The descriptions for that location identify them more prominently as $CaCl_2$—$MgCl_2$ salinity. Again the records are indicative of an increased prevalence related to irrigation.

From about 1200 BC to about 1920 AD nothing about salinity was put into writing (so far as yet discovered). One can suppose that salinity continued to increase in prevalence within lower Iraq.

By lower Iraq we mean the Tigris—Euphrates alluvial plain. This is an area where irrigation, almost from the advent of human occupancy, has been an absolute essential for agriculture. One can make a good case for the impact of soil salinity on the history and totality of settlement in that area [7].

Today, all of lower Iraq, some 72,200 square kilometers, part of it being irrigated, part of it not being irrigated, but all of it irrigated on and off in history for centuries at a time, is classifiable by almost any scientific definition as saline soil.

There are two kinds of soil salinity in Iraq, sodium salt salinity, and calcium-magnesium chloride salinity, the same two kinds as were known about in 1200 BC. There is no sodium carbonate salinity. There is no word in the languages of the country nor in any of the ancient languages which connotes any sodic quality in the soil or any property of causticity or alkalinity — for all the word *al kali* is a pure Arabic word.

The first to call attention to this was WEBSTER [9], the first soil chemist in the service of Iraq. EATON, who travelled widely in Iraq during 1947—48, also called attention to it [3]. In Iraq he saw none of the "black alkali" with which he was thoroughly familiar in California, U. S. A.

Those soils which have high sodium-salt salinity have, of course, high exchangeable sodium percentages in the soil clay complex. But, morphologically and physically they are not sodic soils as we, the authors of this paper, see them. The purpose of this paper is to explain this.

First we should explain the sodic soil characteristics which they do not have.

1. They do not display any surface "skin" of silt and sand after incidents of rain which "skin" is so indicative in sodic soils of clay dispersing and soaking inward.

2. They do not display any eluviated surface layer underlain by any illuviated clay columns with rounded tops or even without rounded tops.

3. Soil columns in the laboratory when leached with the ditch water being used for irrigation never yield turbid leachates. Nor do they yield turbid leachates with distilled water, except in very rare instances.

4. Sodium chloride soils under outdoor conditions of irrigation and normal rainfall rarely ever exhibit pH-values in excess of 8.4. Occasionally under conditions of abnormal impoundments of rainwater, pH values of soil and water may mount to alkalinity with phenolphthalein. This is only temporary. Buringh [1] tells about pH 9 being found in (only) 60 out of 1690 soil pits.

5. The titratable alkalinity in soil saturation extracts is negligible.

6. Humus-stained incrustations are extremely rare. Translocated humus accumulations in profiles are never seen.

At the beginnings of civilizations in lower Iraq the soil most surely was non-saline. The defense of this statement is too complicated to go into here but we are confident of it [7]. We are also confident that the salts which are in the soils today are largely the accretions from the centuries of irrigation.

Lower Iraq is a flat country. The mean fall of it from the points where the Tigris and the Euphrates enter the alluvial plain to where they make their combined exit (Basra), is about 8 cm per kilometer. Subsoils generally are dense. Iraq in all its history has never had a drainage system until some recent beginnings at this. Lower Iraq is a comparatively rainless country, — about 150 mm of annual precipitation coming in the winter half of the year. Soil is rarely wet by rain water deeper than 25 cm. The geography of Iraq [2] is such that ground-water salt discharge if any, must come to light at Basra. The present situation is that only about 20 percent of the salts which come into lower Iraq escape past Basra. Only 7.5 percent of the incoming water escapes past Basra. Above Basra is a large expanse of marsh and a lake, and the water there is sweet water, not salty. Our intrepretation of all of this is that the salts in the water used for irrigation throughout the centuries, is still inside the total land area of lower Iraq to which this water has been on and off and here and there applied.

Fortunately the water used for irrigation in Iraq, — and this is and always has been exclusively the waters of the rivers taken for irrigation mostly during the non-flood months- is a very high quality irrigation water. Data bearing on this and on our subject of sodic soils are shown in Table 1, along with comparison data for the Salt River of Arizona, U. S. A. This latter resource was developed by the U. S. Reclamation Service and put to public use in 1917 as a major portion of the water supply for a 93,000 hectare irrigation project. The project has been successful and prosperous, but is already faced with saline and sodic soil problems, more particularly the latter. The Salt River project has a mean annual precipitation of about 200 mm.

Table 1. reveals two outstanding differences in the waters of the two rivers as they go on the land. One is their $(Ca^{2+} + Mg^{2+})/(Na^{+} + K^{+})$ ratio. The other is the difference in the soluble residues of these waters at what might be called the first evaporation of them. The Salt River Project it should be mentioned, has a drainage system. It can be computed by simple proportion

that had this latter not had a drainage system, it already would have accumulated in 47 years as much salinity as in Iraq from the Tigris water in 365 years.

Our main concern with the data of Table 1. is what they may reveal to us in regard to sodic soil development.

We can be quite sure about it that with the soluble residues of the Tigris water, the Mg^{2+} will displace Ca^{2+} in the clay complex whereby $MgSO_4$ as a constituent will disappear (a fact).

Table 1.

Composition of the Tigris River water being used for irrigation in Iraq[1] and comparative composition of Salt River (Mesa, Arizona, U. S. A.) water

Constituents	Gram Equivalents per Cubic Meter of Water Going on the Land		Gram Equivalents of Residues per Cubic Meter of Soil (1500 kilos)	
	Tigris River Iraq	Salt River Arizona, USA.	Tigris River Iraq	Salt River Arizona, USA.
$MgCO_3$	1.333	1.679	0.144*	—
$CaCO_3$	1.364	2.273	2.553*	3.952*
$CaSO_4$	1.189	2.130	—	0.451*
Na_2SiO_3	—	1.200	—	1.200*
Na_2SO_4	0.156	—	0.890	1.679
NaCl	0.694	12.955	—	11.276
$NaNO_3$	0.040	—	—	—
KCl	—	0.436	—	0.436
$MgCl_2$	—	1.073	0.694	2.753
$MgSO_4$	—	—	0.455	—
$Mg(NO_3)_2$	—	—	0.040	—
Total Insoluble Residues*	—	—	2.697*	5.603*
Total Soluble Salts	4.776	21.746	2.079	16.144
Ratio $\frac{Ca^{2+} + Mg^{2+}}{Na^+ + K^+}$	4.36/1	0.49/1	1.34/1	0.21/1

[1] Water of the non-flood months, June—Feb. Computations by J. C. RUSSEL based on the KNAPPEN—TIPPETTS—ABBETT—MCCARTY "Report on the Development of the Tigris and Euphrates River Systems", Baghdad—New York. (1952).

[2] Computations by J. C. RUSSEL based on CLARKE, F. W. "Data of Geochemistry" U. S. Geological Survey, Bul. 616, 1916, (Analysis H, page 82).

Much of the $MgCl_2$ likewise will disappear and in its place there will be $CaCl_2$ (a fact). Also some of the Na^+ will go into the clay complex to build up sodium saturation percentage and that too is a fact. In the Arizona water, Mg^{2+}, K^+ and Na^+ similarly will displace Ca^{2+}.

At any moment in time after a certain amount of water has been used and a certain total of solubles have been added, there will be, for any certain moisture condition, definite equilibria in the soil solution. For these we can write a GAPON-Equation

$$\frac{K\sqrt{(Ca^{2+} + Mg^{2+})/2}}{(Na^+ + K^+)} = \frac{(Ca + Mg)\,X}{(Na + K)\,X}$$

By a mathematical procedure that we shall not go into here for lack of space, we have computed from Table 1. the data shown in Table 2. The purposes of these data are to reveal:

1. how much of Tigris water is required to bring an illustrative water-laid soil such as that of lower Iraq is, to any particular state (30% sodium saturation in 545 one-meter irrigation years);

2. how more quickly the soil would have been brought to the corresponding sodium saturation percentage had the water been of the quality of the Salt River of Arizona Water (11 one-meter irrigation years);

3. how much safer with Tigris water a soil is, or has been, against conversion to a sodic soil condition than with a water of Salt River quality.

We should say that there is one element of uncertainty in these computations in that with both waters SO_4^{2-} surely will combine with Ca^{2+} to produce $CaSO_4$ precipitate. There is no sure way to put this into the GAPON-Equation. We have left it out, knowing that the effect of so doing is to give sodium saturation percentages somewhat lower than they should be. We know there is calcium sulfate within the lowland Iraq soil, — small amounts usually, in the upper 15 cm, but visible coarse grained amounts at 15—30 cm and deeper.

Table 2.

Computations of surface meters of water required to produce various saturation percentages in a one-meter depth of soil under prescribed hypothetical conditions*

Sodium Saturation Percentage	M^{2+} Concentrations me./liter		M^{2+}/M^{+} ratios		Years of Irrigation (One-Meter Each Year)	
	Tigris Water	Salt River Water	Tigris Water	Salt River Water	Tigris Water	Salt River Water
0.6 (Initial)			4.36	—	0	—
7.2 (Initial)			—	0.49	—	0
10	339	49	1.90	0.53	54	1.0
15	726	168	1.71	0.65	116	3.5
20	1309	235	1.61	0.50	210	4.8
30	2395	547	1.49	0.42	545	11.0

* Assuming 20 me/100 gm as cation exchange capacity. Assuming one-meter depth of water each year being used in a manner to give 22.22% mean moisture content for cation exchange reactions. Assuming a bulk density of 1.500. Assuming that the soils at the moment of settling out of water at producing the soil has the initial values as computed for them. Assuming K in the GAPON-Equation has the value K = 100 [8].

Of course no irrigator ever allows his soil to get into the condition of Table 2. if he can help it. In Iraq, which has no drainage system, the irrigator deliberately puts on enough water at the autumn planting of grain (after the seed is planted) to leach the salts downward into the second meter, if possible. Therein lies another reason why sodic soils do not develop.

All the Tigris water which the irrigator applies has the ions in it shown in Table 1. All this water passing through the surface desalinizes the surface as a first step. Then the M^{2+}-ions in the water, largely Ca^{2+} ions, displace Na^+ in the complex as a second step. These Na^+ ions with their anions to balance are pushed ahead. The result is that what may have been a 30% sodium saturation percentage in the surface as in Table 2. actually gets converted theoretically to as low a value as 0.6 percent. (With water of Salt River quality the theoretical limit of conversion would be 7.2 percent.) At no point in the process can there be dispersion, nor any production of sodic soil.

The real culprit in sodic soil production, starting with a sodium salinity soil high in sodium saturation percentage is the pure water of natural precipitation. In that respect lower Iraq is fortunate in not having much of it. The little that there is (150 mm as an average, occasionally 250 mm, rarely 75 mm at one time) is hardly enough to leach the salts out of the surface to the non-flocculating limit in the first place, nor enough to leach all the gypsum out of the surface soil in the second place. Accordingly the only times that Iraq soils reveal any signs of sodic soil characteristics is when rain water is impounded temporarily and then only for a short period until they become dry and irrigation is resumed or salts arise to the surface by capillarity.

It is pertinent to our subject to compare the Iraq situation with the situation in Nebraska and Wyoming of the U. S. A. The Platte River of Colorado, Wyoming, and Nebraska, U. S. A. crosses Nebraska from west to east, a distance of some 800 kilometers, through a region of gradual climatic change from about 400 mm of mean annual precipitation at the extreme west to about 900 mm at the extreme east. About three fourths of the annual precipitation comes during the summer months of the year. The Platte is in process of up-grading its flow-bed and simultaneously its flood plain. Its velocity is high (mean fall about 1.5 meters per kilometer) whence the flood plain soils at the west are predominantly sandy. Toward the east the soils become heavier and the valley widens, but sandy streaks continue through, and these with their shallow ground water levels are a source of soil salinity for the entire length of the flood plain. The water of the Platte carries a moderate supply of salts, — about 426 parts per million at a mid-point across the state. The solubles contributed to the soil are predominatingly Na_2SO_4. The divalent/monovalent cation ratio is about 0.85/1. Irrigation has been extensive toward the west for over 50 years, the earliest of it dating back into the last century.

So, here we have a process of soil salinization not much complicated by irrigation, extending through a climatic region of changing rainfall from arid to humid, and an attendant desalinization-alkalinization process extending through in reverse direction from humid to arid. The result is a very clear display of consequences.

At the extreme west the soils are exclusively saline-alkaline. At the east, sandy soils on the younger sand sediments are only slightly saline and are non-alkaline. The higher precipitation keeps them continuously leached to the point that neither high salinity nor high alkalinity can develop. The older sand sediments where exposed are leached to the point of being acid. Mostly these older sands are covered with silt and clay alluvium from confluent eastern drainage. Where this alluvium cover is deep the soil is leached to the point of slight acidity. Where it is shallow (1—1 1/2 meters) and broad in expanse as it is extensively within the 800—850 mm precipitation zone, the soils show all the evidence of having been at some earlier period highly saline-alkaline, and subsequently non-saline alkaline to the point of typical and complete solonetz development. Today these soils are mostly well advanced at degradation into "soloths" but occasionally there are clayey spots unprotected by silty overlay where slickness develops during rains with typical white siltyness appearing afterwards. Farther west in the rainfall zone of 500—600 mm there is another extensive area of silt and clay alluvium over sand sediments and this is in an early stage of solonetz development. It is non-saline and highly alkaline. Still lacking any distinct eluviated layer it develops slickness and a badly puddled surface during rains. It has a slow intake of irrigation water. When dry it is extremely dense and solid. In between the west and the east in the zone of about 700 mm of precipitation soils are medium sandy and here developed, on old sand sediments, soils which are typical sandy solonetz.

If we locate lower Iraq into this climatic and soil sequence it would lie far to the west, about in the central part of the State of Wyoming. Wyoming has saline soils abundantly, — $NaCl$ and Na_2SO_4 varieties.

These do not have sodic soil characteristics. Wyoming though does have sodic soils in the same limited rainfall areas (about 175—200 mm annually) contiguous to its saline-alkaline soil but the origins of these are most decidedly related to sodium carbonate-bicarbonate salinity in certain rock formations [5, 6]. The boundaries of these sodic soils wherever they occur can be identified by a certain plant, — greasewood *(Sarcobutus vermiculatus)*. Where the sodic rock formation crop out on sides of slopes, the greasewood appears and one can trace the outcrop across the country by the growth of greasewood.

Iraq has no sodic soil indicator vegetation. Iraq does have an extensive gamut of saline soil indicator vegetation ranging from a salt Bermude grass *Thayil (Cynodon dactylon)* at about the 0.3% limit to a plant which Iraq call *Tartai* at about the 3% salt limit.

Summary

The saline soil situation in Lower Iraq is here explained as largely the consequence of a long duration of irrigation (over 4000 years in places) with an admirable quality of water as regards monovalent-divalent cation ratios in a region of very low annual rainfall. Due to the flatness of the country and the heavy textures of the soil very little of the salts in the irrigation water have ever escaped into the Persian Gulf. During the long intervals of time there have been salt segregations and translocations and arisings to the surface under the influence of elevated water tables and hydraulic gradients. Thereby sodic salts have come to dominate in some places and calcium and magnesium salts in others.

The sodic salinities have high sodium saturation percentages in the cation exchange complex but morphologically, and in respect to problems, they are more to be characterized as saline than as alkaline. Nowhere have the processes of origin led to any areas of non-saline alkaline soils in a true sense. Always the processes of accretions have outrun the processes of losses. Iraq has never had a drainage system until some recent beginnings at this. The mean annual rainfall of Lower Iraq is only about 150 mm.

Some comparisons are made of the sodic soil situation in Iraq with the sodic soil situation of the Nebraska—Wyoming portion of the United States of America. In the latter the climatic and rainfall transitions from east to west in the present and in the distant past have given rise to an almost complete series of sodic soil formations both chemically and morphologically. The climatic position of Lower Iraq in this sequence is far to the west in Wyoming. Wyoming in places has soils which contain Na_2CO_3 but these definitely are the consequence of certain rock strata which contain this chemical.

The possibilities are discussed of Iraq soils becoming non-saline alkaline at sometime in the future as drainage programs are expanded and sodium salts are leached away. Three reasons are offered why no serious problems are expected:

1. The quality of the water which will do the leaching; divalent cations in high excess over monovalent cations, and very little rain. Improvement in sodium saturation percentage is to be expected at the immediate surface first, and later to extend downward.

2. $CaSO_4$ supply in the soil. Along with all the salt accumulations from irrigation there has been a parallel accumulation of $CaSO_4$, much of which is still retained in the upper 30 cm.

3. The gypsum resource of the country. The supply is enormous and is easily accessible.

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Засоленные почвы в Ираке

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Резюме

Появление засоленных почв (saline soils), на территории Нижнего Ирака авторы рассматривают как результаты многолетнего (в некоторых местах орошение имеет 4000 летнюю давность) орошения, проводимого на территориях с чрезвычайно низким годовым количеством осадков, оросительной водой с составом удивительно благоприятным, с точки зрения соотношения одно- и двухвалентных катионов, состава. Благодаря выравненности рельефа и тяжелому механическому составу почвы только незначительная часть солей, содержавшихся в оросительной воде, попадала в Персидский залив. С течением времени подъем уровня грунтовых вод вызвал выделение и перераспределение солей в почве до самой ее поверхности. В результате этого в некоторых местах стали преобладать соли натрия (sodic salts), а в других соли кальция и магния.

Характер содовой засоленности дает преобладание насыщенности почвенного поглощающего комплекса натрием, но с точки зрения морфологии почвы и ее классификации эти почвы скорее относятся к типу засоленных (saline), чем щелочных (alkaline) почв. Процесс развития нигде не указывает на территории, где можно было бы найти незасоленные щелочные почвы (non-saline alkaline soils). Процесс накопления солей везде преобладает над процессом их вымывания. До самых последних времен в Ираке никогда не существовало дренажной системы. Средняя сумма осадков в Нижнем Ираке составляет всего около 150 мм в год.

Авторы проводят сравнение между положением содовых почв (sodic soils) Ирака и содовых почв (sodic soils), имеющихся в районе Небраска—Вайоминг в США. В последнем случае переходный в восточно-западном направлении климат и осадки вызвали создание почти непрерывной серии содово-засоленных почв (sodic soil formation), как в химическом, так и в морфологическом отношениях. С точки зрения климатических условий Нижний Ирак значительно отличается от западной части Вайоминга. В некоторых частях Вайоминга почва содержит Na_2CO_3, но это является следствием наличия этого вещества в почвообразующей породе.

В докладе обсуждается возможность превращения в будущем и иракских почв в незасоленные щелочные почвы (non-saline alkaline-soils) по мере того, как будет создана водосбросная система и вымыты соли натрия. Имеются три причины по которым не следует рассчитывать на возникновение серьезных проблем:

1. Качество воды, используемой для промывания, преобладание двухвалентных катионов над одновалентными, малое количество осадков. Уменьшение процента насыщения натрием ожидается сначала на самой поверхности с тем, чтобы позже распространиться и вглубь.

2. Запас $CaSO_4$ в почве. Параллельно с накоплением солей в результате орошения наблюдается и накопление $CaSO_4$, значительную часть которого все еще можно найти в верхнем 30 см слое.

3. Запасы гипса в стране. Эти запасы громадны и легко доступные.