

THE ALKALI ASPECTS OF THE RECLAMATION OF SALINE SOILS IN IRAQ¹⁾

J. H. BOUMANS and W. C. HULSBOS

SUMMARY

1. Since most of the soils of the Lower Mesopotamian Plain have to be classified as saline-alkali, the question of whether or not these soils would develop in the most unfavourable alkali soils (non saline alkali) if the salinity is reduced by leaching is of great importance. Although a study of the available data on the behaviour of exchangeable sodium in relation to farming practices in Iraq already showed that no great difficulties were to be anticipated, experiments were begun in order to obtain more definite information on the subject.

2. Combined leaching-infiltration rate tests showed that no collapse of the structure occurred, even after the percolation of a depth of several meters water through the soil profile. In field-leaching experiments also no marked structural deterioration occurred during leaching.

3. Analytical data of soil samples taken before and after infiltration rate tests and field-leaching experiments showed that the exchangeable sodium percentage decreased simultaneously with the total salt content, but at a slower rate. This decrease could be explained by the laws governing the cation exchange processes.

4. The minimum value of the exchangeable sodium which could be obtained by infiltration rate tests and field-leaching experiments was about 0.4 m.e. exchangeable sodium per 100 gram soil or an exchangeable sodium percentage from 2 to 4. This minimum value is determined by the quality of the irrigation water and the drainage conditions.

5. The high lime content of the soil (25–27 %) may influence the stability of the structure as it occupies a large part of the soil volume; it may moreover have some importance as a supplier of calcium ions during leaching.

The rather low gypsum content of the surface soil (0–3 %) is soon reduced to zero by leaching and will not have a lasting influence as a supplier of calcium ions.

It is shown that the decrease of the exchangeable sodium percentage can be explained by the favourable qualities of the irrigation water.

6. The relation between pH, salinity and exchangeable sodium has been studied and a correlation has been found, in accordance with the correlation investigated by PASCAUD and MINART for the soils of Northern Africa and France. Based on these correlations the alkalinity level of a soil is known if the pH and the salinity are analysed.

7. From the experimental results presented, it may safely be concluded that no alkalinity problem exists for the saline alkali soils in Iraq. The results further prove that the general fear for the development of alkali soils during the reclamation of saline alkali soils — an opinion found in literature on the subject and expressed by many experts visiting Iraq — is not justified.

8. Finally it may be remarked that some land classification systems applied in Iraq, in which the percentage exchangeable sodium is one of the classification criteria, need revision.

The same holds for the economic aspects of reclamation as far as these are based on the supply of gypsum amendments.

CONTENTS

1. LIST OF SYMBOLS AND UNITS	226
2. INTRODUCTION	226
3. THE SALINE ALKALI SOILS OF IRAQ	227
4. PRELIMINARY INVESTIGATIONS INTO THE PROBLEM	227
5. RECENT LEACHING EXPERIMENTS	229
5.1 Infiltration rate and exchangeable sodium	229
5.2 Exchangeable sodium behaviour with leaching field plots	231
6. RELATIONSHIP OF EXCHANGEABLE SODIUM, pH AND SALINITY	233
7. REFERENCES	234

¹⁾ Received for publication July 28, 1960.

1 LIST OF SYMBOLS AND UNITS

EC	electrical conductivity	mmhos/cm at 25° C
EC _e	EC of the saturated soil extract	mmhos/cm at 25° C
E.S.P.	exchangeable sodium percentage	%
S.A.R.	sodium adsorption ratio, $\frac{Na}{\sqrt{(Ca + Mg)/2}}$	ionic concentrations in m.e./l
m.e./l	milliequivalent per litre
meshara	local area unit	2500 sq.m.

2 INTRODUCTION

It is well known that a soil containing a high percentage of sodium on the exchange complex becomes deflocculated and is characterized by an unstable soil structure, low permeability and low air content. The soil surface may become dark coloured due to dispersed organic matter and forms under dry conditions hard prismatic units with rounded smooth surfaces. Clay particles may wash down in the profile causing an incipient clay pan.

Soils in this condition are called alkali soils. They are extremely difficult to handle as they are plastic and sticky when wet, and hard and compact when dry.

The alkali soils are well described by KELLY (1951) and occur over considerable areas in the western part of the United States, India, Pakistan, Egypt, Russia, Hungary etc. Particularly, since artificial irrigation was introduced large areas of formerly productive soil have become unproductive because of alkalinity.

If a soil high in exchangeable sodium is also saline, the soil particles remain flocculated, due to the ionic concentration of the surrounding soil solution and no such features as described above will develop as long as the ionic concentration of the soil solution remains sufficiently high. However, if in such a saline alkali soil the salts are leached and the saline soil solution is replaced by a non-saline solution, the conditions may be created for the development of an alkali soil with all its characteristics and low agricultural value.

A considerable amount of confusion exists as to the terminology of the soils here described. The terms alkali, black alkali and solonetz are not well defined and are often used in slightly differing senses.

Lately the terms black alkali for dark coloured soils with a high exchangeable sodium percentage and white alkali for a non-dark coloured saline soil, which is not necessarily alkali, have been abandoned by most authors. The term solonetz is mainly an indication of the typical morphological status of an alkali soil.

In the following discussions the terminology proposed by the U.S. Salinity Laboratory will be used (U.S.D.A. Agriculture Handbook no. 60, 1954):

Non-saline non-alkali soils. Electrical conductivity of the saturation extract (EC_e) less than 4 mmhos/cm at 25° C and less than 15% sodium adsorbed

Saline soil. The EC_e more than 4 mmhos/cm, the exchangeable sodium on the adsorption complex.

percentage (E.S.P.) less than 15.

Alkali soils. The EC_e less than 4 mmhos/cm, the E.S.P. more than 15. The pH of the saturated paste is usually more than 8.5.

Saline alkali soils. The EC_e more than 4 mmhos/cm, the E.S.P. more than 15, while the pH is lower than 8.5.

The limit of 15% exchangeable sodium between alkali and non-alkali soils is based on research in the United States. This limit depends on many different local conditions and should not be taken as a rigid general rule. VAN DER MOLEN for instance (1957) reports that in Holland deflocculation may occur with much lower percentages.

3 THE SALINE ALKALI SOILS OF IRAQ

Salinity surveys have been performed in different project areas in Iraq. They revealed that the soils of the Plain of the Tigris and Euphrates rivers South of Baghdad are highly saline. Nearly 2 million mesharas (500,000 ha), or more than 60% of the important areas of Dujailah, Nahrwan and Gharraf Extension, have an electrical conductivity of the surface soil higher than 16 mmhos/cm (HULSBOS and BOUMANS, 1960). These soils are unsuitable for crop growth even for very tolerant crops.

With very few exceptions these highly saline soils are all alkaline. Although the pH of the soil paste seldom exceeds 8.5, exchangeable sodium percentages over 50 are not rare. The average exchangeable sodium percentage for all saline soils is estimated as being somewhere between 20 and 25.

Some soil survey reports mention the occurrence of non-saline alkali soils (BURINGH, 1958) and classify them with names such as alkali-flats, alkali-basin soils etc. These observations and classifications, however, are mainly based on morphological characteristics of the soil profile and not on the results of chemical analyses. In our experience very few non-saline alkali soils occur. In 25 soil profiles and pits in the Nahrwan area none of the almost 100 samples taken at different depths proved to be non-saline alkali; of more than 150 samples of 12 selected topsoils and approximately 50 sampled profiles only 2 topsoils could be classified as non-saline alkali in the Adhaim area; and in 50 sampled profiles in the Ishaqi area no non-saline alkali soil could be found (BINNIE, DEACON and GOURLY, vol. II, 1956). Of the many hundreds of samples in the Dujailah Experimental Farm also not one could be named non-saline alkali (Dujailah Experiments, report 4, 1957, report 6, 1959).

As by far the greater part of the saline soils in Iraq had to be classified as saline alkali soils, knowledge of their behaviour during reclamation became of primary importance. In particular the question of whether these soils would develop into a non-saline alkali soil through leaching, with all its repercussions on structure, permeability and workability, had to be answered.

4 PRELIMINARY INVESTIGATIONS OF THE PROBLEM

From the moment that the first analytical results of investigations of the exchangeable sodium percentages were reported, and the high level of the E.S.P. values became known, many experts on soils and drainage who were working in the country or were on visits were seriously concerned. Consequently, in many reports and memoranda a warning was given, that if the leaching of these soils was not carried out with the utmost care, using gypsum or other suitable amendments, reclamation would fail (Z.A.D. irrigation projects, 1956).

On the other hand, a number of observations held out much hope that the situation was not as serious as predicted and that leaching of these soils could probably be performed without encountering any great difficulties

related to the development of alkali soils. The most important considerations in this respect are:

- a As has already been mentioned, out of the numerous soil samples analysed, practically none showed the true alkali characteristics i.e. a low salt content together with a high exchangeable sodium value, although analyses of low as well as high saline soils were represented. This is a remarkable fact as leaching, although without drainage, is regularly practised by the local farmers to reduce the salt content of the surface soil before planting. During the fallow period the salt content of the surface soil may reach high values through capillary rise from a shallow salty groundwater table which in turn is fed by seepage from irrigated neighbouring plots. Salinities of the surface soil higher than $EC_e = 30$ mmhos/cm may be reached in this way during fallow periods of regularly irrigated soils. Before sowing this high salinity is reduced by one or two heavy irrigation gifts. If there was a serious danger of true alkali soils developing, many such soils would actually be present due to this regular leaching by farmers.
- b All the soils of the Lower Mesopotamian Plain contain abundant calcium. Gypsum is present in most subsoils and partly in the surface soils, although in low concentration (HULSBOS and BOUMANS, 1960). In the extremely saline areas calcium chloride is often present in important quantities. The major part of the calcium is, however, in the form of carbonates. Usually from 20 to 30% of the soil consists of lime (Dujailah Exp. 6, 1959). Although calcium carbonate, due to its low solubility has little value as a supplier of Ca-ions in the exchange process, it still has some value (VAN DER MOLEN, 1957), especially where it is fine grained. It was found that the calcium carbonate in the alluvial soils in Southern Iraq is almost equally divided over the different soil fractions, occurring partially in particles of 2 micron and less in clay containing soils.
- c The irrigation water has favourable characteristics. Table 1 gives the composition of the Tigris river water at Baghdad over 1949. As shown by the data of the table the irrigation (leaching) water may be a valuable supplier of Ca-ions in the leaching process. Furthermore the ratio $(Ca + Mg)/Na$ of the water is very favourable as is shown by the low sodium adsorption ratio (U.S.D.A., 1954).

Table 1 Composition of Tigris water sampled at Baghdad 1949.

	Minimum (May)	Maximum (December)	Average year
Salt p.p.m. . . .	180	370	250
Ca m.e./l	2.2	2.3	2.5
Mg m.e./l	0.9	1.8	1.4
Na m.e./l	0.2	1.4	0.9
S.A.R.	0.2	1.0	0.6

As during leaching the salty soil solution is replaced by leaching water with a high $(Ca + Mg)/Na$ ratio it is not very likely that a sodium soil could develop. For instance, a soil in equilibrium with a soil solution which has a sodium adsorption ratio,

$$Na/\sqrt{(Ca + Mg)/2} = 1,$$

(concentrations in m.e./l) is, according to the U.S. salinity laboratory, expected to have

an exchangeable sodium percentage of approximately only 1 (U.S.D.A., Agrics. Handbook no. 60, 1954).

The empirical relationships, found by the U.S. salinity laboratory, are only valid, strictly speaking, for the soils which have been investigated. The equation adopted by the U.S. salinity laboratory based on these observations, however, is of a similar type to that proposed by Gapon. Recently the general value of this equation has been extensively investigated and it has been shown that the Gapon type equations are of practical value in describing the cation exchange equilibrium (BOWER, 1959).

All these arguments lead us to believe that there is probably no alkali problem at all in reclaiming the saline alkali soils of Iraq. This conclusion found support in the results of some preliminary leaching experiments made in 1955 (Dujailah Exp. 2, 1955). These experiments showed that together with the salinity the average E.S.P. of the soil layers 0–30 cm and 30–60 cm dropped from 36 to 9 and from 36 to 21, in a 21 day leaching period.

However, even after these experimental results were reported, the fear of alkali problems consequent on the reclamation of the soils of Iraq remained. In 1956 a consulting firm (BINNIE, DEACON and GOURLY, 1956) still recommended that gypsum should be used at the rate of 1.7 tons per acre for each milliequivalent of Na per 100 grams of soil in which the E.S.P. was to be reduced. Also BURRING (1960) was not convinced by the experimental results. His opinion that the analytical data have to be doubted seems however not justified. The analytical results are confirmed by all later laboratory work on this subject.

5 RECENT LEACHING EXPERIMENTS

Since the preliminary experiments in 1955, more systematic and detailed studies of the different aspects of the reclamation have been started. In these studies special attention has been paid to the alkali problem. Several experiments were laid out to study the behaviour of exchangeable sodium during leaching and the possible deterioration of the soil structure and permeability. The results of these experiments, which were in full agreement with the previous findings, are reported in the following paragraphs.

The experiments started in 1956 on the Dujailah drainage and land reclamation experimental farm (Dujailah exp. 1, 1954). The farm is located on an extremely saline alkali silty loam soil, of a type which occurs over large areas in Southern Iraq.

Combined infiltration-leaching tests were made in order to study the influence of leaching on the stability of the soil structure which was evaluated by changes of the infiltration rate. In field experiments the change in exchangeable sodium and salt content proceeding from different leaching practices were studied.

5.1 *Infiltration rate and exchangeable sodium*

Table 2 shows the results of a number of infiltration rate tests of Dujailah soils and of 2 Abu Ghraib soils (A-1 and A-2). The infiltration rate tests were performed over periods ranging from less than one week to more than seven weeks. The tests were carried out with two concentric cylinders, with diameters of 50 cm and 70 cm respectively. The cylinders were placed over the soil and carefully pressed down into the soil for about 5 cm. A constant waterhead of about 10 cm was maintained in both cylinders. The speed at

Table 2 Infiltration rate in cm/day in relation to total depths infiltrated.

Total water depth infiltrated cm	Test number									
	VI-5	A-1	VI-B	VI-10	A-2	VI-9	VI-7	III-3B	II-3	III-6B
0- 50	1.5	2.1	9	10	7	8	18	15	38	38
50-100	—	3.0	8.5	5	—	7	21	17	34	35
100-150	—	—	4	6	—	7	15	—	31	39
150-200	—	—	2.5	6.5	—	15	8	—	27	41
200-250	—	—	—	9	—	—	5	—	31	41
> 250	—	—	—	7	—	—	6	—	38	46
Total hours	744	932	786	1225	145	576	762	126	670	239
„ cm in- } ...	45	95	176	337	41	201	296	82	882	396
Avg. infiltr. } ... cm/day	1.5	2.5	5	6.5	7	8.5	9.5	16	32	40

which water soaks into the soil through the inner cylinder was measured and is given as the infiltration rate.

The average infiltration rate for the different tests differed widely. No correlation could be found between infiltration rate and texture (table 3), nor did the infiltration rate correlate with the exchangeable sodium figures. It is possible that the depth of the sub-soil water table has some influence on the intake rate. The exchangeable sodium decreasing during the tests, seems to reach a minimum at 0.4 m.e. per 100 gram soil or an exchangeable sodium percentage between 2 and 4.

In most cases the infiltration rate remained practically constant during the whole observation period. In some cases a decrease was observed, which was, however, not very serious, and was probably due to a rising subsoil water table during the observation period and not to a structure deterioration.

The results of these tests thus give a strong evidence that infiltration with large amounts of water, which can be considered as fast leaching, did not cause a serious deterioration of the soil structure nor a decrease in soil permeability.

In field leaching trials also no deterioration of the soil structure could be observed. These trials were performed on highly saline alkali soils in Du-jailah, both by leaching a bare soil without a crop stand and by over-irrigating a crop.

Table 3 Soil analyses, 0-5 cm, samples taken after infiltration-leaching tests.

Test number	VI-5	A-1	VI-8	VI-10	A-2	VI-9	VI-7	III-3B	II-3	III-6B
Clay %	17	51	30	—	48	44	28	38	25	34
Clay + silt % ...	77	94	87	—	95	87	83	90	85	83
Exch. Na %	4	2	4	—	2	5	7.5	4	3	2.5
Exch. Na m.e./ } 100 g	0.4	0.4	0.7	—	0.4	0.9	1.0	0.8	0.4	0.4

In one of the trials gypsum was applied at a rate of 1500 kg/meshara and sulphur at a rate of 300 kg/meshara. During a complete irrigation period the surface soil of the treated basins was observed and was compared to the non-treated basins. No visible difference in soil structure and intake rate nor any kind of difference could be observed as a result of the amendments.

These observations agree with the results of investigations in the Gharraf Extension Project (T.A.M.S., 1957). The soils contained no gypsum and the effects of leaching the alkali from the soil without chemical amendments was considered questionable. Here a drainage test was performed in which one plot was leached untreated, while the second had a quantity of gypsum mixed into the surface soils prior to leaching. The results of this test also indicated that there was little difference to be noted between the results of the two plots and that the soils could be reclaimed by leaching.

In Annanah heavily saline alkali basin soils with a bad structure have been reclaimed. No marked structure deterioration occurred during leaching. Leaching was more difficult, however, and these soils, because of their heavy texture, will always have to be handled with care (Annanah exp. 1, 1958 and HULSBOS and BOUMANS, 1960).

5.2 Exchangeable sodium behaviour with leaching field plots

During field leaching experiments soil samples were taken at different intervals. These samples were analysed for salt content and exchangeable sodium.

In table 4 the results of these analyses are summarised. Up to 60 cm depth

Table 4 Decrease of exchangeable sodium and salt during leaching.

Depth soil layer cm	0-30		30-60		60-100		100-150	
	EC _e	ESP	EC _e	ESP	EC _e	ESP	EC _e	ESP
Before leaching . . .	106	34	37	38	34	44	36	44
After 12 days leaching; 15 cm drainage ¹⁾	6.5	15	13.5	33	—	—	—	—
After 42 days leaching; 52 cm drainage	3.0	8	2.6	23	—	—	—	—
After 69 days leaching; 84 cm drainage	2.6	7	2.2	21	7.5	38	24	43
After 69 days leaching and 93 days cropping	3.8	5.5	2.0	20	—	—	—	—
After 69 days leaching and 3 cropping seasons	3.6	4.2	3.9	10	8.1	19	16	21

¹⁾ 15 cm drainage indicates that during the given period a waterdepth of 15 cm was discharged by the field drains.

the figures given are the averages of at least 20 samples, each consisting of 9 subsamples; the deep samples are averages from 6 to 18 samples taken at different locations (Dujailah exp. 6, 1959).

The data leaves no doubt that during leaching the E.S.P. decreases simultaneously with the salt content, though at a lesser rate. In all places were

Table 5 Average gypsum content of Dujailah soils.

Depth (cm)	Plot XI and XII			Plot I (before leaching)			Plot I (after leaching)		
	m.e./ 100 g	%	No. of samples	m.e./ 100 g	%	No. of samples	m.e./ 100 g	%	No. of samples
0- 30	7	0.60	22	11	0.95	9	0	0	9
30- 60	5	0.43	22	3	0.26	15	0	0	9
60-100	6	0.52	22	19	1.64	15	12	1.03	7
100-150	19	1.64	22	29	2.50	15	19	1.64	7
150-200	19	1.64	22	12	1.03	15	8	0.69	7

the samples are taken the E.S.P. dropped considerably. In agreement with the results of the infiltration-leaching tests discussed already, this data also indicates that it will be difficult to decrease the E.S.P. below a value of 4.

The gypsum content of the soil is strongly effected by leaching. This is clearly demonstrated by the data of table 5. After leaching with a depth of 140 cm water the gypsum content of the whole sampled profile was considerably lower. In the top 60 cm of the soil the gypsum content was even reduced to 0. This means that the part played by gypsum as a supplier of Ca-ions to replace sodium at the exchange complex during reclamation, can be an important factor only in the early stages of the leaching process, as the gypsum is washed downwards very quickly. The relatively low gypsum content of the soils can not be made responsible for the important and lasting decrease in exchangeable sodium when leaching is continuous.

The decrease in exchangeable sodium during leaching can in theory be understood. During leaching, the saline soil solution is gradually replaced by irrigation water. This will have a similar effect to diluting the soil solution with irrigation water. Table 6 demonstrates how the E.S.P. of a soil decreases if the soil solution is diluted. The E.S.P. values were calculated according to the empirical relationship between S.A.R. and E.S.P., as given by the U.S. salinity laboratory (U.S.D.A., 1954).

The actual leaching process is more complicated than is assumed here, since salts may go into solution and because interactions of exchangeable and soluble cations will alter the ionic concentrations of the soil solution. Moreover, the equilibrium conditions are usually not met in a fast leaching process. The general trend, however, which is shown in table 6, viz. that diluting a soil solution will result in a decrease in E.S.P. will be the same for actual leaching.

Table 6 Decrease of exchangeable sodium if soil solution is diluted with irrigation water according to table 1.

	EC mmhos/cm	Na me/l	Ca + Mg me/l	SAR	ESP
Soil extract before leaching	110	600	250	53	43
Diluting 2 ×	60	300	127	38	34
„ 4 ×	31	151	66	26	27
„ 10 ×	15	61	29	16	18
„ 20 ×	8	31	17	11	13

6 RELATIONSHIP EXCHANGEABLE SODIUM, pH AND SALINITY

As has already been mentioned, many soil scientists have tried to find adsorption equations to express the relationship between soluble and exchangeable cations. Various results are obtained with the different equations, especially if mono- and bivalent ions are present. Some success has been obtained in the U.S.A. by a semi-empirical approach (U.S.D.A., 1954).

For the Dujailah soils not yet enough accurate analytical data has been collected to permit the establishment of such a relation. Instead, a correlation was sought between exchangeable sodium, pH and salinity. Presumably such a correlation exists since both the E.S.P. and the salinity decreased during leaching. We were encouraged by the fact that a correlation between pH, salinity and alkalisation had already been established for different soils in North Africa and in France (PASCAUD et MINART, 1958).

The relationship between pH, E.S.P. and EC is plotted in figure 1. Lines of equal alkalinity could be drawn through the observation points. In figure 1 the analytical results of all samplings of the experimental fields from the start of the experiments in spring 1956 up to the end of 1957 are shown. The pH is measured in the paste and the conductivity in the saturated extract.

In analysing the graph it appears to be based on two tendencies. The first is the known fact that the pH decreases with an increasing salt content, all other factors excluded. This is caused by an increasing replacement of adsorbed H-ions by cations of the saline soil solution.

The second, and most interesting, tendency is the increase in exchangeable sodium with increasing salinity and a constant pH (figure 2). Which is in agree-

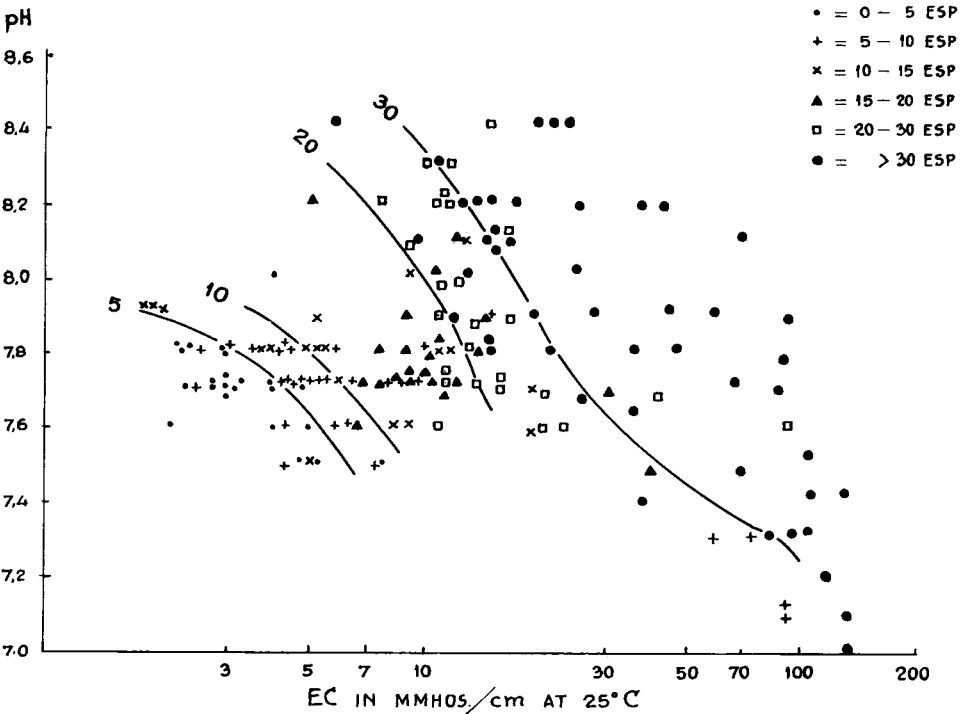


FIG. 1 RELATIONSHIP BETWEEN SOIL SALINITY, pH AND EXCHANGEABLE SODIUM.

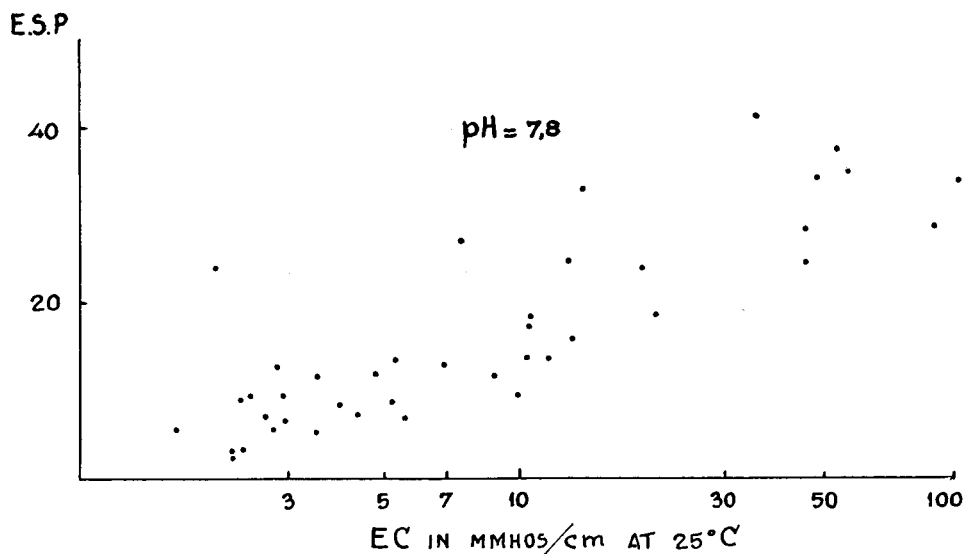


FIG. 2 RELATIONSHIP BETWEEN SOIL SALINITY AND EXCHANGEABLE SODIUM AT A CONSTANT pH.

ment with the previously discussed results. From these two tendencies it follows that all other factors remaining constant an increase in exchangeable sodium will result in an increase in pH. This is also known and explained by hydrolyses, which provokes the formation of sodium hydroxide.

Thus, by this correlation study, the results of the leaching tests, which showed a simultaneous decrease in E.S.P. and salinity, are confirmed.

A practical application of the data of figure 1 is that on the basis of two very simple measurements, the pH and the EC, the alkalinity level can be predicted. Since graphs for different soils and soils of a different salinity type are found to be similar figure 1 may be considered valid for all saline soils in Iraq.

According to PASCAUD and MINART no such relationship could be found for sandy and organic soils.

7 REFERENCES

- Dujailah experimental reports, Development Board and Ministry of Development, Iraq :
 Report 1, Detailed proposals to start experimental work (1954).
 Report 2, Results of leaching of some soils along the maindrain (1955).
 Report 3, Summary of some results over 1955 and 1956 (1957).
 Report 4, Results of a leaching test on 6 mesharas tile-drained salty land (1957).
 Report 5, Crop yields and reclamation (1958).
 Report 6, Salts in agricultural soil (1959).
 Report 7, Consumptive use of crops (1959).
 Annanah experimental reports, Development Board and Ministry of Development, Iraq :
 Report 1, Results of leaching and the first summer crops (1958).
 Seminar on drainage and land reclamation, Development Board and Ministry of Development, Iraq (1958).
 BINNIE, DEACON and GOURLY : Z.A.D. irrigation projects vol. 1, 11, 111 (1956).
 BURINGH, P. : Soils and Soil Conditions in Iraq, Baghdad (1960).
 BURINGH, P. : Soil survey of the Hills-Kifl project (Iraq), Ministry of Agriculture, Baghdad (in press).

- HULSBOS, W. C. and J. H. BOUMANS : Leaching of saline soils in Iraq. *Neth. Journal of Agr. Sci.* (1960).
- KELLY, W. P. : Alkali soils, New York (1951).
- MOLEN, W. H. VAN DER : De inundaties gedurende 1944-'45 en hun gevolgen voor de landbouw, deel IX, thesis, Wageningen (1957).
- MCDONALD and partners : Diyalah and Middle Tigris projects, report 2 (1958).
- PASCAUD et MINART : Corrélation entre le pH, salinité et alcalinité, Communication pour le colloque UNESCO sur les problèmes de salinité dans des régions arides, Téhéran (1958).
- TIPPETS-ABBETT-McCARTHY-STRATTON : Symposium, Drainage problems in connection with irrigation projects of Southern Iraq, Baghdad (1957).
- U.S.D.A. Diagnosis and Improvement of saline and alkali soils, Agriculture Handbook no. 60 (1954).