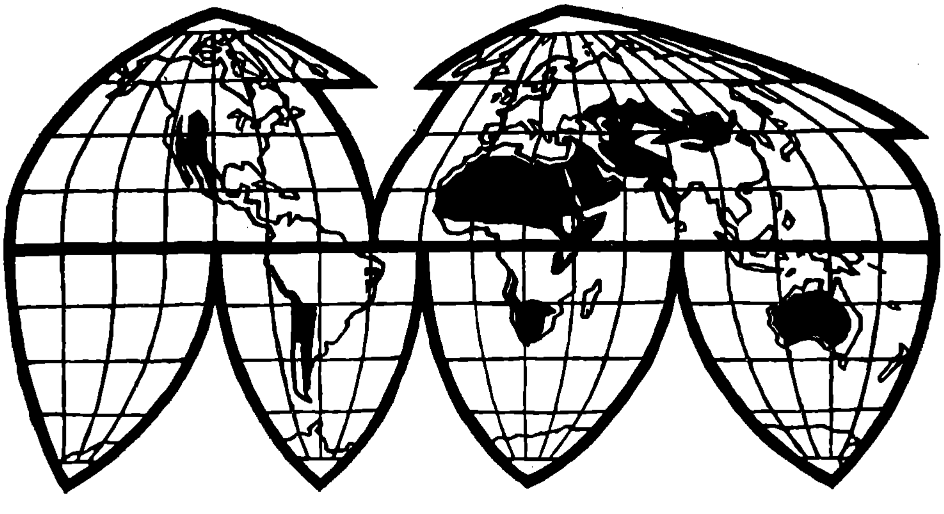
ARID ZONE RESEARCH
RECHERCHES SUR LA ZONE ARIDE

SALINITY PROBLEMS IN THE ARID ZONES

Proceedings of the Teheran Symposium

LES PROBLÈMES DE LA SALINITÉ DANS LES RÉGIONS ARIDES

Actes du colloque de Téhéran



UNESCO

ARID ZONE RESEARCH — XIV
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PROCEEDINGS OF THE TEHERAN SYMPOSIUM

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LES PROBLÈMES DE LA SALINITÉ DANS LES RÉGIONS ARIDES
ACTES DU COLLOQUE DE TÉHÉRAN

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- I. *Reviews of research on arid zone hydrology*
  Compte rendu des recherches relatives à l'hydrologie de la zone aride
- II. *Proceedings of the Ankara Symposium on Arid Zone Hydrology*
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- XV. *Plant-water relationships in arid and semi-arid conditions. Reviews of research*
  Échanges hydriques des plantes en milieu aride ou semi-aride. Compte rendu de recherches
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The reviews of research are published with a yellow cover; the proceedings of the symposia with a grey cover.

Les comptes rendus de recherches sont publiés sous couverture jaune; les actes des colloques, sous couverture grise.

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FOREWORD

The object of the programme on which Unesco embarked with the establishment, in 1951, of an Advisory Committee on Arid Zone Research is to promote and encourage research in the various branches of science with a bearing on aridity problems. Its longer-term object, however, is not only to enlarge our knowledge but also to help bring about an improvement in man's living conditions, in desert and semi-desert areas in particular; and its conversion in 1957 into a Unesco "Major Project" enabled its scope to be widened and the benefit of its results to be made more directly available to those parts of the world where aridity problems are most pressing.

Our present knowledge is the outcome of a multitude of highly specialized efforts, and in certain branches the very mass of information available is a source of grave difficulties to research workers. For this reason, Unesco has undertaken the publication of synoptic reviews of research devoted, each year, to branches of study specially concerned with the arid zones: hydrology, plant ecology, human and animal ecology, climatology, etc.

The problem of the utilization of saline water, either directly by plants or after demineralization, is of considerable importance in arid lands, and a synoptic review of the research conducted on this question has already appeared in the present series (Utilization of saline water. Reviews of research, 1957).

A number of scientific symposia have been organized by Unesco under the arid zone research programme in order to provide an opportunity for the presentation of the latest work on the subject and to establish direct and fruitful contacts between research workers in all countries. The problems raised by soil and water salinity in the arid zones were considered by the advisory committee to be of such importance that an international scientific gathering should be devoted to the subject.

The Symposium on Salinity Problems in the Arid Zones, organized by Unesco, was held in Teheran from 11 to 15 October 1958 at the invitation of the Iranian Government. The opening meeting took place in the Avicena Hall of the University of Teheran, under the chairmanship of Professor Fohrad, the vice-chancellor of the University, and was attended by the Prime Minister, H.E. Dr. Eghbal, the Ministers of Agriculture and Education, and many other leading personalities.

Eighty-three specialists from 20 countries took part in the symposium. The Iranian Government had made itself responsible for inviting specialists from the region extending from North Africa to the Middle East and South Asia, as well as a few European specialists, while Unesco had arranged for the participation of scientists from America, Western Europe, Australia, and the U.S.S.R. In addition, a number of specialists attended as representatives of the institutions to which they belonged.

The papers had been grouped into four sections: I. Hydrology with reference to salinity; II. Physiology of plants and animals in relation to consumption of saline water; III. Irrigation with brackish water and saline soils; IV. Demineralization of saline water.

The present volume contains the text of these papers, together with a brief summary of the discussions to which they gave rise. As with the proceedings of previous symposia, the texts have been reproduced in the original language (English or French), with a summary in the other language.

The success of the symposium would have been impossible without the signal efforts of the Iranian authorities, who enabled a large number of scientists from foreign countries to attend, and who saw to the practical arrangements. Professor A. H. Behnia, a member of the advisory committee and executive secretary of the organizing committee for the symposium, was one of the main architects of that success.

In his closing address at the end of the symposium, H.E. Dr. Raadi, who was at that time chairman of Unesco's Executive Board, stressing the importance for mankind of the problem of soil and water salinity, which went back several thousand years, and the help provided by modern science in solving that problem, described the event as a splendid example of what could be achieved by effective co-operation between a Member State, assisted by its National Commission, and Unesco.

AVANT-PROPOS

Le programme dont l'Unesco a entrepris la mise en œuvre en créant, en 1951, un Comité consultatif de recherches sur la zone aride vise à promouvoir et à encourager les recherches relatives aux diverses disciplines scientifiques dont relèvent les problèmes de l'aridité. Son but lointain n'est pas seulement d'enrichir nos connaissances mais aussi de contribuer à l'amélioration des conditions de vie de l'homme, notamment dans les régions désertiques et semi-désertiques. La transformation, en 1957, de ce programme en un "projet majeur" de l'Organisation a permis de lui donner une ampleur plus grande et de faire bénéficier plus directement de ses résultats les régions du monde où les problèmes de l'aridité sont les plus aigus.

Nos connaissances actuelles sont l'aboutissement d'une multitude de travaux hautement spécialisés et, dans certaines disciplines, l'abondance même des données est la source de graves difficultés pour les chercheurs. C'est pourquoi l'Unesco a entrepris de publier des inventaires de recherches consacrés, chaque année, à des disciplines qui s'intéressent particulièrement à l'étude des zones arides: hydrologie, écologie végétale, écologie humaine et animale, climatologie, etc.

Le problème de l'utilisation des eaux salines, soit directement par les plantes, soit après déminéralisation, est d'une importance considérable dans les pays arides et un inventaire des recherches effectuées à ce sujet a été publié dans la présente collection (Utilisation des eaux salines. Compte rendu de recherches, 1957).

En vue de permettre la présentation des travaux les plus récents et d'assurer un contact direct et fructueux entre les chercheurs de tous les pays, un certain nombre de colloques scientifiques ont été organisés par l'Unesco, dans le cadre du programme de recherches sur les zones arides. Il a paru au Comité consultatif que l'importance même des questions posées par la salinité des terres et des eaux dans ces régions demandait qu'une réunion scientifique internationale y fût consacrée.

Sur l'invitation du gouvernement iranien, le colloque sur les problèmes de la salinité dans les zones arides, organisé par l'Unesco, a eu lieu à Téhéran, du 11 au 15 octobre 1958. La séance inaugurale a eu lieu dans la salle Avicenne de l'Université de Téhéran, sous la présidence du professeur Fohrad, recteur de l'Université, en présence du premier ministre, S. Exc. le Dr Eghbal, du ministre de l'agriculture, du ministre de l'éducation nationale et de nombreuses personnalités.

Quatre-vingt-trois spécialistes de vingt pays ont pris part au colloque. Le gouvernement iranien s'était chargé d'inviter des spécialistes de la région qui s'étend de l'Afrique du Nord au Moyen-Orient et à l'Asie méridionale, ainsi que quelques spécialistes européens. De son côté, l'Unesco avait assuré la participation au colloque d'hommes de science d'Amérique, d'Europe occidentale, d'Australie et d'URSS. Enfin, un certain nombre de spécialistes avaient été délégués par les institutions auxquelles ils appartenaient.

Les communications avaient été groupées en quatre sections: I. Hydrologie et salinité; II. Physiologie des animaux et des végétaux consommant de l'eau salée; III. Irrigation à l'eau saumâtre et sols salés; IV. Déminéralisation de l'eau salée.

Le présent volume contient le texte de ces communications et un bref compte rendu des discussions auxquelles elles ont donné lieu. Comme pour les actes des précédents colloques, les textes ont été reproduits dans la langue originale (français ou anglais) et accompagnés d'un résumé dans l'autre langue.

Le succès du colloque n'aurait pu être assuré sans l'effort remarquable des autorités iraniennes, qui ont rendu possible la participation d'un nombre important d'hommes de science étrangers et qui se sont chargées de l'organisation matérielle des travaux. Le professeur A. H. Behnia, membre du Comité consultatif et secrétaire exécutif du comité d'organisation du colloque, a été l'un des artisans essentiels de ce succès.

Au cours de l'allocution de clôture du colloque, S. Exc. le Dr Raadi, alors président du Conseil exécutif de l'Unesco, rappelant l'importance du problème plusieurs fois millénaire de la salinité des sols et des eaux et soulignant l'intérêt des solutions apportées par la science moderne, a exprimé l'opinion que cette manifestation constituait un excellent exemple de ce qui peut être réalisé grâce à la coopération efficace d'un État membre, aidé de sa commission nationale et de l'Unesco.

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I

HYDROLOGY WITH REFERENCE TO SALINITY

HYDROLOGIE ET SALINITÉ

INTRODUCTION:
HYDROLOGY WITH REFERENCE TO SALINITY

by

F. DIXEY and S. H. SHAW

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Many arid zone hydrological problems are to a large extent problems of salinity, and it is very fitting that these should be made the subject of a special symposium. It is unfortunately the case that the arid zones of the world are very often those in which the unfavourable climatic conditions—insufficient and seasonal rainfall—are aggravated by the fact that the underground waters when found are often too saline to be of use; fortunately fresh waters do sometimes occur, occasionally in surprising quantity, but at times under conditions not readily understood.

In the search for low-salinity waters in arid regions reliance must still be placed on a thorough hydrogeological investigation of the occurrence of saline and fresh waters so that prediction of new examples of the relatively rare occurrences of fresh water can be made, as on the lines of the work of Shotton and others in North Africa [12] [1] and of Koonin in Central Asia [6]. This search can be aided by geophysical observations. Also, the possibility needs to be kept in mind that shallow saline ground waters may be due to the concentration by evaporation of fresh-water springs, which themselves may be susceptible to tapping at depth, as in the case of the Chott ech Chergui scheme of Algeria.

The relations of fresh to saline waters in arid areas are highly variable; saline waters may overlie fresh as in the example just cited, or fresh waters may overlie saline when downward-percolating rain water comes to rest on inland or coastal saline waters; again, in coastal areas the relations between fresh and saline waters may be much complicated by the over-pumping of the fresh waters.

Recently, in the south-central part of the Kalahari region of Bechuanaland, Boocock and Van Straten [1] have found that fresh water occurs in Middle Ecca beds underlying Upper Ecca carrying saline waters; the fresh water is derived from stream-bed outcrops of the Middle Ecca occurring a few miles east of the boreholes which yielded the new observations. It has proved possible to shut off at least the greater part of the saline water in the upper part of the bore-holes.

In so far as underground-water sources are concerned the geologist employs essentially the same fundamental principles in his search for water, whether it be fresh or saline; and the same principles govern the quantitative testing of the sources when they have been found. Mann [7] has recently shown that from careful examination of aerial photographs it is possible to estimate the quantity and quality of waters available in dry regions. For example, a small spring appears on the airphoto as a small spot of phreatophytes, i.e. plants that depend on fresh water at shallow depths, whereas a larger spring will show a line of phreatophytes extending downstream. A one-acre patch of phreatophytes would require a minimum of 1 million gallons of water a year and probably much more, and the water used by one square mile of cottonwoods or salt cedars during a growing season would supply the needs of cities with 23,500 or 28,000 inhabitants respectively for one year, assuming a consumption of 145 gallons per head per day [9].

In the alluvial fans of closed desert basins with no ground-water outlet, an upper concentric strip of phreatophytes would indicate shallow fresh water, while downslope these plants would be replaced by halophytes where the salinity has been increased by high evaporation rate.

Mr. J. H. Whitney, of Aramco, has informed F. Dixey that in Nejal, in north-central Arabia, the local people use a certain running gourd vine as an indicator of ground-water, and with its aid they locate wells, 50 ft. or more in depth, by following its tap root down to water level. Wells over 200 ft. deep are reported to have been located in this way.

Koonin [6] has described lenses of fresh water in the zone of aeration in sands, and beneath barchan accumulations, in the Karakum desert of central Asia; he believes that in the formation of these lenses gravitational infiltration is to be ruled out, and that they are formed by the condensation of vapours derived from waters,

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[1] The figures in brackets refer to the bibliography on page 23.

often saline, at greater depths. Furthermore, if sufficient information could be accumulated on the thermal, lithological and hydrogeological conditions involved, the possibility of the control or at least the stimulation of production of such waters could be considered.

Where water found in the course of exploratory drilling operations proves to be more or less heavily mineralized the geologist is at once faced with a number of problems. If the mineralization is too high to enable the water to be used he must be prepared to offer an opinion as to the likelihood of the condition being a general one and as to the probable extent of the area within which further exploration is likely to give the same unsatisfactory results, or where more favourable results might be expected. This will involve him in a careful mapping programme and in special studies of the source and character of the water and of the containing sediments or other rocks. If the mineralization of the water is appreciable but not great enough to prevent the water from being used he will be faced with additional problems. During the drilling of wells he will require samples of the water obtained from different depths in the aquifer to see if the mineralization increases with depth, as it often does in coastal regions. During pumping tests he will again require frequent samples of the water to test the variation in its content of dissolved salts. He may perhaps observe seasonal variations in salinities and have to attempt to correlate these with, or separate them from, the effect of varying pumping rates, and with this information, and sometimes without it, he will probably have to decide what is the maximum safe yield of wells if the salinity of the water is not to increase beyond a given figure. In pumping operations, having decided what is a safe yield, he may be pressed to agree to a higher rate of withdrawal or may be asked to say whether the quality of the water will return to its original state when a period of overpumping is ended.

Important in this connexion is the work of Santing [11] in showing that, where contamination of fresh water by underlying salt water has taken place in a well, it is sometimes possible to control the upconing of the salt water by simultaneous pumping of the salt and the fresh water by means of separate pumps in the one well; by this method it has proved possible to restore to use wells that had been abandoned owing to contamination.

In the Taranto region of southern Italy, where in fissured limestone terrain fresh water derived from rainfall rests on sea water, Zorzi [14] has shown that by careful control of pumping it was possible to raise sufficient fresh water, free of contamination, to irrigate about 30,000 ha. This result is of particular interest to a number of Mediterranean countries and islands. The estimation of the ground-water resources of karstic regions, with special reference to Hungary, has recently been considered by Kessler [5].

Many of these are examples of problems common to arid-zone hydrology but absent or only marginally important in regions of more temperate climate; they all lead to the necessity for special studies concerning the origin and composition of underground waters.

Additional special problems arise when mineralized waters are required for agricultural purposes in arid climates. The exact physical character and chemical composition of the soil is known to have a most important bearing on the problems of irrigating with saline or mineralized waters. Base exchange reactions may result in disaggregation and destruction of the crumb structure of the soil with a consequent reduction in its porosity and the eventual destruction of its crop-bearing capacities; this tendency may be reversible if the soil can be washed at intervals with fresh water, as for instance during rain-storms in occasional wet season conditions. Even if damage of this kind does not occur an unsuitable soil profile or the existence of a hard-pan or other impermeable medium in the sub-soil may lead to a retention of the mineralized irrigation waters within the surface zone of capillarity and the eventual deposition of harmful salts in soil by surface evaporation. Methods of preventing an undue rise in the water table brought about by the irrigation itself must therefore be studied, and it may be difficult to reconcile the need to supply a given quantity of water for the requirements of a crop with the need to keep the quantity below the amount that will bring about the undesirable effects of too much evaporation at the surface. The composition of the irrigation water itself and particularly the relative proportions of sodium and calcium and of sulphate and chlorine ions are of prime importance when considering the tolerance of particular crops, as well as having an important bearing on the base exchange reactions in the soil already referred to.

Thus geologists and agriculturists both find themselves involved in complex problems of physical chemistry, and whether they have the services of specialists in that subject or not satisfactory answers to many of their practical problems are dependent upon the results of experimental tests. To equip themselves better for their particular work it therefore becomes necessary in arid zones for geologists and hydrologists to study and understand soil types and the methods and techniques of the soil surveyor, and for the agriculturist to become something of an hydrologist and geologist if he is to appreciate the special limitations that the environment is imposing on him.

Geologists and hydrologists too have no doubt often been baffled by the difficulty of obtaining a clear-cut answer as to whether or not a particular water will be suitable for the growth of a particular crop. Here again the question of dependent variables comes in; for example, higher sodium to calcium ratios can be better tolerated in irrigation waters of low than of high salinities [10]. Moreover, the effective concentration of salts in the water is unfortunately not merely that in the irrigation water itself but also that in the soil solution just before irrigation—on impermeable soils this concentration may be 10 times greater than in the irrigation water. This observation clearly points to the need for a greater knowledge of the processes and rates at which initially fresh water becomes charged with soluble materials from the soil or the underground aquifer.

A considerable amount of $CaCO_3$ in a soil will not necessarily provide sufficient calcium ions to prevent undesirable base exchange between ions of the saline water and those of the clay minerals present in the soil [13]. The suitability of the water is often not so much dependent on total solids as on the proportions of ions, and sometimes even the addition of ions may be beneficial.

In spite of the pressing need for a great deal more information on almost all aspects of these problems there is fortunately enough known in many cases to enable some of the worst effects of the use of mineralized waters in arid zones to be mitigated. Proper management of pumping rates through different seasons may enable the same quantity of water to be drawn without deterioration in quality, as shown by the pumping experiments already referred to; or damage from the deposition of salts in the soil may be mitigated by a proper irrigation regime.

The demineralization of salt water in its various aspects promises to be of great assistance in arid regions, and it is fitting that it should be studied in this symposium.

In general the removal of the dissolved mineral content of a water involves the application, directly or indirectly, of energy, and the provision of energy costs money. Furthermore, the places where the provision of fresh instead of saline water would be of most benefit are often those remote from sources of power and where the low standard of living of the people makes them least likely to be able to afford the cost of that power even if means could be found to make it physically available. It would be a great mistake, however, for those concerned with irrigation problems in relatively poor agricultural areas to neglect the investigation of desalting methods, even if it looks at present as though the cost of these would limit their application to industrial uses. Once satisfactory processes have been developed it is not too much to hope that in the long run they will be improved and cheapened and that in due course, and with the advent of power from atomic sources, it may be possible to desalt waters economically for extensive agricultural applications in the arid zones. Numerous plants for the desalinification of water by various methods are now in operation, as described in papers submitted to this symposium, and valuable experience in their operation will doubtless be gained in the near future and made available for application in the arid regions generally.

With reference to the relation of climate to groundwater salinity, it is of interest that the Eocene limestones of Israel and Jordan tend to yield plentiful water of good quality in the better-watered parts of those countries, while generally yielding much more saline waters in the more arid southern and eastern parts; other similar instances could no doubt be quoted. Doubtless the more arid climate is directly or indirectly responsible for the more saline conditions; it is possible that, amongst other factors, the total volume of water percolating underground is smaller in the arid zones and that, by taking up the same weight of soluble material from the aquifer, it thereby becomes more highly mineralized; but possibly the waters are already charged with saline material before they start percolating to the underground reservoir. The complications of this subject, the many gaps in our knowledge, and their importance in arid zone problems have been well brought out by Eriksson in his recent contribution to Unesco's review of research in climatology [4].

Burdon and Mazloum [3], in considering the groundwaters of Syria, have concluded that the chemical composition of the aquifers is the most important factor controlling the chemical composition of the groundwater, although it is admitted that the recharge water may contain up to 200 ppm. of soluble salts derived from leaching in the zone of precipitation, and that the chemical changes take place more rapidly in regions of low rather than high rainfall. As total soluble salts increase, the water changes from a primary carbonate water through an intermediate stage with no predominant anion to a final stage in which total soluble salts are very high and the chlorides predominate.

On the other hand, Koonin [6], while agreeing with the commonly accepted view as to the importance of the nature of the containing rocks on the composition of ground-water, considers that the main factor is independent of the composition of the rocks and comprises underground evaporation, which leads to continuous increase in concentration; it can take place at any depth, and under suitable conditions the vapours can be condensed at higher levels in the ground, or can be transpired.

As regards the influence of air-borne soluble sea salts, although the more immediate effect of their precipitation in arid zones may be to produce soil salinity problems, its bearing on the hydrology of underground waters, and hence its importance to geologists, must not be overlooked. While average figures must be treated with care because conditions of precipitation are much affected by topography as well as by geographical position and other factors, it is nonetheless interesting to note that Eriksson [4, pp. 170–174] estimates the annual precipitation of sea salt as perhaps 3 kg./ha. for the drier steppe regions south of the Sahara, 2 kg./ha. in the Kalahari, 1 kg./ha. in the high plateaux of Iran and Iraq and as little as 0.5 kg./ha. in the Gobi Desert. An annual deposition of 1 kg./ha. does not amount to more than a tenth of a gram per square metre, but if we are dealing with even the shorter spans of geological time this may assume importance. For example, in 10,000 years, which is not an unreasonable time for a given region to have remained within one climatic regime, the accumulation, at 1 kg./ha. per annum, on one square metre would amount to a kilogramme and if, as is likely in arid zones, there is on balance a net accumulation of salts, it is clear that conditions conducive to saline ground-waters are present, quite apart from any mineralization the rain-water might acquire by solution from the rocks themselves.

Minor climatic cycles are of great importance in arid regions, for in many cases it is only in periods of unusually prolonged heavy rainfall that the ground-water is augmented; the view has been expressed by Martin [8] that in the Kalahari such recharge takes place only at intervals of about 10 years; ordinarily, the rainfall does not penetrate the sand to a depth of more than about 20 ft. In the Nevada desert there is no significant recharge to ground-water when the annual precipitation is less than 8–10 in., which is no more than is needed to satisfy the evapotranspiration requirements of the local xerophytic vegetation [9].

The attention that has recently been paid to the question of the recharge of aquifers is particularly likely to emphasize the practical importance of knowing in more detail the mechanisms by which waters become mineralized in their passage downwards through the ground. In a recent paper Buchan [2] has shown that even in the temperate conditions of the United Kingdom rain-water acquires chemical characteristics closely approaching those of the underlying ground-water after it has traversed only the first few feet of the soil and sub-soil overlying the aquifer. He ascribes this to the initial carbon dioxide content of the rain-water and considers that unless some fresh cause for reactivation exists subsequent modifications take place mainly by addition of solutions from other strata. Similar observations were made some years ago by Schoeller. Under more arid conditions, as recorded by Burdon and Mazloum [3], infiltrating rain-water may acquire a salinity of 200 ppm. before reaching the ground-water.

When the salinities of near-surface waters in arid zones are studied some puzzling features sometimes become apparent. In the Abyan Delta of the Aden Protectorate, for instance, the salinities of these waters vary rapidly within short distances and through a wide range, and this may seem strange in view of the fact that the delta forms one hydrological unit. The ultimate source of the water in the Abyan Delta is certainly the rainfall in the hinterland. The primary channels by which that water is led to the delta are the two wadis whose debouchment from the hills has formed the delta itself, and the underground water of the area is essentially confined to the sub-surface flow in the gravels, sands and clays of the delta. We must therefore assume that the observed wide variations in the amount and composition of the soluble material observed in the ground-water are due to variations in the nature of the sediments comprising the deltaic complex, and to local variations in the rates of evaporation. Buchan's observations that percolating rain-waters very quickly assume the main character of their immediate environment may therefore be relevant and an indication of a promising line of inquiry. The possibility of such rapid changes is of course of vital importance in connexion with recharge works and it might well be that a scheme of this nature could be nullified, or produce the opposite effect intended, if by ill-change waters were made to percolate through strata which immediately contributed a large quantity of freshly dissolved material of an undesirable character.

It is of interest to record that artificial recharge of ground-waters did not begin with the operations in Europe and America in recent years, but has been practised for some centuries in the Karakum desert, where the inhabitants lead the water from clay lenses on to sands, where it is absorbed and later recovered by means of wells [6].

Consideration of the array of papers to be presented at this symposium justifies the hope that they and the ensuing discussions will greatly advance our knowledge of the problems of salinity in arid regions.

INTRODUCTION: HYDROLOGIE ET SALINITÉ

par
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Un grand nombre des problèmes d'hydrologie qui se posent dans la zone aride concernent, dans une large mesure, la salinité, et il était particulièrement indiqué qu'un colloque spécial leur soit consacré. En effet, il arrive très souvent que, dans les zones arides, des conditions climatiques défavorables (précipitations insuffisantes et saisonnières) se trouvent encore aggravées du fait que l'eau présente dans le sous-sol est trop minéralisée pour être utilisable; heureusement, il arrive qu'on y rencontre de l'eau douce – parfois en quantités étonnantes – mais dans des conditions qui sont souvent mal comprises.

Lorsqu'on recherche des eaux faiblement salines dans une région aride, il est toujours bon de se fonder sur une étude hydrogéologique approfondie des ressources en eau saline et en eau douce, étude qui permet de prévoir les emplacements – relativement rares – où l'on pourra trouver de nouvelles nappes d'eau douce, selon la méthode appliquée par Shotton et d'autres en Afrique du Nord [12][1] et par Koonin en Asie centrale [6]; ces recherches peuvent être facilitées par des observations géophysiques. De même, il importe de se rappeler qu'une eau souterraine saline à faible profondeur peut provenir de la concentration, par évaporation, d'une eau douce qu'il est possible de capter en profondeur, comme c'est le cas aux alentours du Chott-ech-chergui en Algérie.

La position relative des eaux salines et des eaux douces dans les régions arides est très variable; il arrive que les eaux salines se trouvent au-dessus des eaux douces, comme dans l'exemple qui vient d'être cité, ou au-dessous lorsque l'eau de pluie s'infiltre jusqu'à venir reposer sur des eaux salines, le long d'une côte ou à l'intérieur des terres. D'autre part, dans les régions côtières, la position relative des eaux douces et des eaux salines est parfois très complexe, du fait du pompage excessif des premières.

Boocock et Van Straten [1] ont récemment constaté, dans la partie centre-sud de la région de Kalahari, au Bechuanaland, la présence d'eau douce dans des couches d'Ecca moyen, au-dessous de couches d'Ecca supérieur contenant des eaux salines; l'eau douce provient d'affleurements d'un lit de cours d'eau de l'Ecca moyen, localisés à quelques kilomètres à l'est des trous de sondage qui ont permis ces constatations nouvelles. On a réussi à isoler, au moins en majeure partie, l'eau saline dans la partie supérieure des trous de sondage.

En ce qui concerne les sources souterraines, le géologue applique en général les mêmes règles fondamentales pour rechercher de l'eau, qu'elle soit douce ou saline, et pour déterminer le débit possible des sources repérées. Mann [7] a récemment démontré la possibilité d'évaluer la quantité d'eau présente dans une région sèche, et sa qualité, en soumettant à un examen attentif des photographies aériennes. C'est ainsi qu'une petite source se signalera sur le cliché par une petite tache de phréatophytes, c'est-à-dire de plantes qui ont besoin d'eau douce à faible profondeur, tandis qu'une source plus importante sera révélée par une bande de phréatophytes s'étendant en aval. Un acre (0,4 hectare) de phréatophytes exige au minimum un million de gallons d'eau par an, et probablement beaucoup plus (1 gallon = 4,54 litres); quant à la quantité d'eau consommée pendant une saison de croissance par un mille carré de peupliers ou de tamaris (1 mille carré = 2 589 km^2), elle suffirait aux besoins d'une ville de 23 500 habitants dans le premier cas, de 28 000 habitants dans le second, si l'on compte 145 gallons par personne et par jour [9].

Dans les cônes d'éboulis des bassins désertiques fermés où les eaux souterraines n'ont pas de possibilité d'écoulement, une bande concentrique de phréatophytes à la partie supérieure révélerait la présence d'eau douce à faible profondeur, tandis que plus bas, là où la salinité est plus grande du fait d'un taux élevé d'évaporation, ces plantes seraient remplacées par des halophytes.

M. J. H. Whitney, de l'Aramco, nous a fait savoir qu'au Nejal, dans le centre de l'Arabie septentrionale, les habitants décèlent la présence d'eaux souterraines grâce à une plante rampante de la famille des Cucurbi-

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[1] Les chiffres entre crochets renvoient à la bibliographie, p. 23.

tacées et découvrent des points d'eau situés à 15 mètres de profondeur et plus en suivant les racines pivotantes de cette plante jusqu'au niveau de la nappe d'eau. Il paraît qu'on aurait ainsi découvert des points d'eau à plus de 60 mètres de profondeur.

Koonin [6] a décrit des "lentilles" d'eau douce situées dans la zone d'aération des sables, au-dessous d'amoncellements de barchanes, dans le désert de Karakoum (Asie centrale): à son avis, on ne saurait attribuer la formation de ces "lentilles" à l'infiltration due à la gravité et il faut en chercher l'origine dans la condensation de vapeurs provenant d'eaux, souvent salines, situées à de plus grandes profondeurs. En outre, si l'on pouvait rassembler des données suffisantes sur les conditions thermiques, lithologiques et hydrogéologiques de ce phénomène, on pourrait envisager la possibilité de régler, ou tout au moins de stimuler, la production d'eaux de ce genre.

Lorsque l'eau découverte au cours d'explorations par forages se révèle plus ou moins fortement minéralisée, un certain nombre de problèmes se posent immédiatement au géologue. Si cette eau est trop fortement minéralisée pour être utilisable, il doit être en mesure de préciser si, à son avis, cette caractéristique est locale ou non, et d'indiquer approximativement le périmètre à l'intérieur duquel d'autres forages risquent de donner le même résultat. A cet effet, il lui faut dresser une carte minutieuse de la région et soumettre à une étude spéciale l'origine et les caractéristiques de l'eau, ainsi que la roche-magasin, sédimentaire ou autre. En outre, si le degré de minéralisation n'est pas assez élevé pour rendre l'eau impropre à tout usage, le géologue devra faire face à d'autres problèmes encore. Pendant le forage des puits, il recueillera des échantillons d'eau à différents niveaux, afin de voir si la minéralisation augmente avec la profondeur, comme c'est souvent le cas dans les régions côtières. Au cours des essais de pompage, il prélèvera aussi de nombreux échantillons afin de mesurer les variations de la teneur en sels dissous. Il observera peut-être des fluctuations saisonnières de la salinité: en pareil cas, il devra déterminer dans quelle mesure ces fluctuations suivent les variations du taux de pompage. Enfin, une fois muni de ces renseignements (ou même sans avoir pu les obtenir), il sera probablement incité à indiquer la quantité maximum d'eau qu'on pourra extraire sans s'exposer à voir la salinité de l'eau dépasser une valeur donnée. Et il se peut qu'on le presse ensuite de consentir pendant quelque temps à un pompage plus intensif, ou qu'on lui demande si, après la fin d'une période de pompage intensif, l'eau pourra retrouver sa qualité primitive.

En ce domaine, Santing [11] a fait œuvre utile en démontrant que, dans les cas de contamination de l'eau douce d'un puits par l'eau saline sous-jacente, il est parfois possible de lutter contre la montée en cône de l'eau saline en pompant simultanément l'eau saline et l'eau douce à l'aide de pompes distinctes dans le même puits; cette méthode a permis de remettre en usage des puits qui avaient été abandonnés pour cause de contamination.

Dans la région de Tarente (Italie méridionale), où, dans un terrain calcaire fissuré, l'eau de pluie repose sur de l'eau de mer, Zorzi [14] a démontré qu'on pouvait, par un pompage minutieusement réglé, extraire suffisamment d'eau douce non contaminée pour irriguer environ 30 000 hectares. Ce résultat intéressera tout particulièrement un certain nombre de pays et d'îles de la région méditerranéenne. Kessler [5] a récemment étudié l'évaluation des ressources en eaux souterraines des régions karstiques, surtout dans le cas de la Hongrie.

Il y a là plusieurs exemples de problèmes d'hydrologie qui sont communs à toutes les régions arides, mais qui ne se posent guère, ou point, dans les zones plus tempérées; et, pour résoudre tout problème de ce genre, on doit entreprendre des études spéciales sur l'origine et la composition des eaux souterraines.

D'autres problèmes viennent encore s'y ajouter lorsque des eaux minéralisées doivent être utilisées à des fins agricoles dans les régions arides. On sait en effet que les propriétés physiques et la composition chimique du sol jouent un rôle très important quand on veut irriguer des terres avec de l'eau saline ou minéralisée. Les réactions d'échange de bases peuvent provoquer la désagrégation et la destruction des granules dont le sol est formé: la porosité se trouvant diminuée, la terre risque alors de perdre sa fertilité, à moins qu'elle ne soit lessivée de temps à autre par de l'eau douce, s'il se produit par exemple des orages. Même si une telle détérioration n'est pas à craindre, un profil défavorable des strates, ou la présence d'une croûte calcaire ou d'une autre couche imperméable dans le sous-sol, peut provoquer la rétention des eaux d'irrigation minéralisées dans la couche superficielle où joue la capillarité. Des sels nuisibles s'y accumulent alors par suite de l'évaporation en surface. Il importe par conséquent de rechercher les moyens de prévenir un relèvement exagéré du niveau hydrostatique dû à l'irrigation; dans le cas de certaines cultures exigeant une forte quantité d'eau, il peut d'ailleurs se révéler difficile d'éviter les conséquences néfastes d'une évaporation trop intense à la surface. La composition de l'eau d'irrigation elle-même, et en particulier le rapport existant entre les ions sodium et calcium, d'une part, et les ions sulfate et chlore, d'autre part, exerce une influence déterminante sur la tolérance de telles ou telles plantes, sans parler des effets importants qu'il a sur les réactions de substitution déjà mentionnées.

Ainsi, les géologues et les agriculteurs se trouvent les uns et les autres aux prises avec des problèmes complexes de chimie physique et, qu'ils puissent ou non faire appel au concours de spécialistes de cette discipline, beaucoup des difficultés auxquelles ils se heurtent ne peuvent être résolues que par des études expérimentales.

Pour mieux se préparer à jouer leur rôle dans les régions arides, il faut donc que les géologues et les hydrologues étudient les différents types de sols ainsi que les méthodes et techniques de la pédologie et que les agriculteurs s'initient aux rudiments de l'hydrologie et de la géologie afin de comprendre les limitations spéciales que le milieu leur impose.

Géologues et hydrologues sont souvent déconcertés par l'apparente difficulté qu'on éprouve à déterminer avec certitude si telle eau convient à la culture d'une plante donnée. Ici se pose à nouveau la question des "variables dépendantes"; par exemple, on peut tolérer dans l'eau d'irrigation un rapport sodium-calcium relativement élevé s'il s'agit d'une eau faiblement saline [10]. En outre, le taux réel de salinité de l'eau ne dépend pas uniquement, malheureusement, de celui de l'eau d'irrigation proprement dite, mais aussi de celui de la solution du sol immédiatement avant l'irrigation – et, dans un sol imperméable, ce deuxième taux peut être dix fois supérieur au premier. Il faudrait donc déterminer avec plus de soin qu'on ne l'a fait jusqu'ici comment et dans quelles proportions une eau d'irrigation, douce à l'origine, se charge de substances solubles empruntées au sol ou à la nappe souterraine.

Une forte teneur du sol en $CaCO_3$ n'apportera pas nécessairement un nombre suffisant d'ions calcium pour empêcher des réactions de substitution nuisible entre les ions de l'eau saline et ceux des minéraux argileux présents dans le sol [13]. Bien souvent, la bonne qualité de l'eau ne dépend pas tant de sa teneur totale en matières solides que de la proportion relative d'ions, et il arrive même qu'on ait intérêt à ajouter des ions.

Bien qu'il soit urgent de rassembler maints autres éléments d'information sur presque tous les aspects de tels problèmes, nous en savons heureusement assez pour pouvoir atténuer très souvent les conséquences les plus fâcheuses de l'emploi d'eaux minéralisées dans les régions arides. En faisant varier, selon la saison, le taux de pompage de façon appropriée, on peut extraire davantage d'eau sans en abaisser la qualité, ainsi que l'ont montré les expériences de pompage déjà mentionnées; de même, il est possible, en adoptant un régime d'irrigation bien conçu, de limiter les dégâts causés par le dépôt des sels dans le sol.

La déminéralisation des eaux salines, sous tous ses aspects, offre de grandes possibilités pour les régions arides et il est particulièrement indiqué de l'étudier au cours de ce colloque.

De façon générale, pour extraire de l'eau les minéraux qu'elle contient en dissolution, il faut utiliser de l'énergie directement ou indirectement, ce qui est onéreux. De plus, les régions où il serait le plus souhaitable de disposer d'eau douce, et non d'eau saline, sont souvent éloignées des sources d'énergie, et tellement pauvres que, même s'il était possible d'y transporter de l'énergie, la population ne pourrait se procurer les fonds nécessaires à son utilisation. Cependant, ceux qui s'occupent des problèmes d'irrigation dans des zones agricoles relativement pauvres auraient grand tort de négliger l'étude des méthodes de dessalage, même s'il semble à l'heure actuelle qu'en raison de leur coût élevé ces méthodes ne peuvent être utilisées qu'à des fins industrielles. En effet, si des procédés satisfaisants sont mis au point, on peut légitimement espérer qu'ils seront peu à peu rendus plus efficaces et moins coûteux, si bien qu'un jour, compte tenu des nouvelles ressources fournies par l'énergie atomique, la désalinisation de l'eau pourra s'effectuer de façon assez économique pour être susceptible de larges applications agricoles dans les régions arides. De nombreuses installations de désalinisation, utilisant diverses méthodes, fonctionnent aujourd'hui et font l'objet de descriptions dans les communications présentées à ce colloque; grâce à elles se développera une expérience précieuse qui pourra être mise en pratique dans l'ensemble des régions arides.

Au sujet du rapport existant entre le climat et la salinité des eaux souterraines, il est intéressant de signaler que les calcaires de l'Éocène en Israël et en Jordanie donnent généralement de grandes quantités d'eau de bonne qualité dans les parties les mieux arrosées de ces deux pays, alors que, dans les zones plus arides du Sud et de l'Est, il produisent davantage d'eau saline. On pourrait sans aucun doute citer d'autres exemples de ce phénomène. Il est clair que l'aridité du climat en est directement ou indirectement responsable; peut-être résulte-t-il notamment du fait que, le volume total de l'eau percolant jusque dans le sous-sol étant plus faible dans les terres arides, cette eau devient plus fortement minéralisée, le même poids de matériaux solubles se retrouvant dans la couche aquifère. Mais il est possible aussi que les eaux soient déjà chargées de sels avant de commencer à percoler vers la nappe souterraine. La complexité de ces questions, l'importance qu'elles présentent pour la solution des problèmes de la zone aride et les nombreuses lacunes qui subsistent dans nos connaissances à cet égard ont été bien mises en lumière par Eriksson dans *Climatologie: compte rendu de recherches*, récemment publié par l'Unesco [4].

Burdon et Mazloum [3], étudiant les eaux souterraines de la Syrie, sont arrivés à la conclusion que la composition chimique des nappes aquifères est le plus important des facteurs dont dépend la composition chimique de l'eau souterraine, bien qu'il soit admis que l'eau de recharge peut contenir jusqu'à 200 ppm de sels solubles provenant de la lixiviation dans la zone de précipitation et que les modifications chimiques se produisent plus rapidement dans les régions où la pluviosité est faible que là où elle est forte. A mesure que s'accroît la quantité totale de sels solubles, l'eau qui était carbonatée à l'origine passe par un état intermédiaire sans anion prédominant pour acquérir finalement une très forte teneur en sels solubles, avec prédominance de chlorures.

En revanche, Koonin [6], tout en partageant l'opinion générale sur l'importance de la nature des roches-magasins pour la composition de l'eau souterraine, estime que le facteur principal ne réside pas dans la composition des roches mais dans l'évaporation souterraine qui entraîne une concentration toujours croissante; cette évaporation peut se produire à n'importe quelle profondeur et, dans des conditions favorables, la vapeur d'eau peut se condenser plus près de la surface ou être évacuée par transpiration.

En ce qui concerne les sels marins solubles transportés par l'atmosphère, bien que leur dépôt dans les régions arides puisse créer dès l'abord des problèmes de salinité des sols, il importe de ne pas oublier leur influence sur l'hydrologie des eaux souterraines et, par voie de conséquence, leur intérêt pour les géologues. Les moyennes doivent être, dans ce domaine, utilisées avec circonspection, car les quantités précipitées varient dans une mesure considérable en fonction de la topographie, de la situation géographique et d'autres facteurs. Il n'en est pas moins intéressant de constater que, selon Eriksson [4, p. 187 à 192], la quantité de sels marins apportée chaque année atteint quelque 3 kg par hectare dans la région sèche des steppes au sud du Sahara, 2 kg par hectare dans le Kalahari, 1 kg par hectare sur les hauts plateaux de l'Iran et de l'Irak, et 0,5 kg par hectare seulement dans le désert de Gobi. Un dépôt annuel de 1 kg par hectare ne représente guère que 1 dg par mètre carré, mais peut devenir important si l'on prend en considération une période géologique, même relativement courte. Par exemple, en dix mille ans – laps de temps pendant lequel on peut raisonnablement compter que le régime climatique d'une région donnée ne varie pas – le sel déposé sur 1 m^2 représente 1 kg, au taux de 1 kg par hectare et par an; et si, comme il est probable dans les zones arides, la déperdition subie durant la même période est nettement plus faible, il est clair que les eaux souterraines doivent se saliniser, en dehors même du processus de minéralisation des eaux de pluie par dissolution des sels contenus dans les roches.

Les cycles climatiques secondaires présentent une grande importance dans les régions arides car, en bien des cas, c'est seulement pendant les périodes de forte pluviosité d'une durée anormale que le volume des eaux souterraines augmente; Martin [8] a émis l'avis que, dans le Kalahari, cette recharge ne se produit qu'à intervalles d'environ dix ans; d'ordinaire, l'eau de pluie ne pénètre pas dans le sable à plus de 6 mètres de profondeur. Dans le désert du Nevada, il n'y a pas de recharge appréciable des eaux souterraines si les précipitations sont inférieures à 20 ou 25 centimètres, ce qui suffit tout juste à satisfaire aux besoins d'évapotranspiration de la végétation xérophyte locale [9].

Les études entreprises depuis peu sur la question de la recharge des nappes aquifères ont toute chance de mettre en lumière l'utilité pratique d'une connaissance plus détaillée du processus de minéralisation des eaux au cours de leur passage à travers le sol. Dans un récent rapport, Buchan [2] a montré que, même dans un pays à climat tempéré comme le Royaume-Uni, l'eau de pluie acquiert des caractéristiques chimiques très voisines de celles de l'eau souterraine dès qu'elle s'est enfoncée de quelques pieds dans le sol et le sous-sol au-dessus d'une nappe aquifère. Il attribue ce phénomène au fait que l'eau de pluie contient à l'origine de l'acide carbonique, et il estime que, si cette eau n'est pas réactivée, les modifications ultérieures sont dues principalement à l'addition de solutions provenant d'autres strates. Des observations analogues ont été faites il y a quelques années par Schoeller. Dans un climat plus aride, comme l'ont indiqué Burdon et Mazloum [3], l'eau de pluie qui s'infiltre peut acquérir une salinité de 20 degrés français (200 ppm) avant d'atteindre la nappe souterraine.

Lorsqu'on étudie la salinité des eaux proches de la surface dans les régions arides, on enregistre parfois certaines anomalies. Dans le delta d'Abyan (protectorat d'Aden) par exemple, la salinité de ces eaux varie sensiblement et de façon brusque en des points très proches les uns des autres, ce qui peut paraître étrange étant donné que cette zone forme une seule unité hydrologique. Les eaux existant dans ce delta tirent certainement leur origine des précipitations qui tombent dans l'hinterland; les principaux canaux d'acheminement sont les deux oueds qui, en débouchant des montagnes, forment le delta lui-même, et l'eau souterraine se trouve presque uniquement près de la surface dans les couches de gravier, de sable et d'argile. Il apparaît donc que les importantes différences enregistrées en ce qui concerne la quantité et la nature des éléments solubles contenus dans les eaux souterraines sont dues à des variations des types de sédiments qui composent le sol, ainsi qu'à des variations locales du taux d'évaporation. Les observations de Buchan, selon lesquelles les eaux de pluie qui s'infiltrent acquièrent très rapidement les caractéristiques essentielles de leur nouveau milieu, peuvent donc être pertinentes et ouvrir aux chercheurs de fécondes perspectives en la matière. L'existence de fluctuations aussi brusques présente manifestement une grande importance pour les travaux entrepris en vue de la recharge de la nappe souterraine: en effet, ces travaux pourraient se révéler inutiles, ou même aller à l'encontre du but visé, si, par malchance, on faisait percoler les eaux à travers des strates où elles se chargeraient immédiatement d'une grande quantité de matériaux de caractère nuisible.

Il est intéressant de signaler que la recharge artificielle des eaux souterraines, qui n'a été entreprise en Europe et en Amérique que récemment, est pratiquée depuis plusieurs siècles dans le désert de Karakoum, où les habitants conduisent l'eau accumulée dans des "lentilles" d'argile vers les sables qui l'absorbent; elle est récupérée plus tard au moyen de puits [6].

A voir le nombre des communications qui seront présentées à ce colloque, on peut espérer que leur contenu et les débats auxquels elles donneront lieu permettront de réaliser de grands progrès dans la connaissance des problèmes que pose la salinité dans les régions arides.

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HYDROLOGIE ET SALINITÉ DES EAUX SOUTERRAINES

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INTRODUCTION

Bien que le but de cet exposé soit, comme l'indique son titre, d'étudier les problèmes de la salinité des eaux souterraines dans ses rapports avec l'hydrologie, il ne nous a pas semblé possible de passer sous silence la question de la salinité des eaux de surface, cette salinité étant, ou bien la conséquence de la salinité des eaux souterraines (rivières et lacs salés), ou bien un facteur de très grande importance pour la salinité des nappes, comme c'est le cas dans les estuaires.

ORIGINE DES MATIÈRES DISSOUTES DANS LES EAUX SOUTERRAINES

L'eau qui pénètre dans le sol entre en réaction avec les corps qui composent l'écorce terrestre, et cette réaction est évidemment fortement influencée par la composition chimique et la structure physique des roches. D'autres facteurs interviennent également parmi lesquels nous citerons la température, la pression, la vitesse de l'eau et par conséquent la durée du contact, les matières déjà dissoutes.

Au sujet de la nature des roches et de leur structure physique, on est amené à considérer séparément les roches ignées et les roches sédimentaires. Si la proportion absolue de ces dernières roches est assez réduite, on observera cependant qu'elles occupent une partie importante de la surface terrestre (75% d'après certains) et, dans ces conditions, ces roches ont une importance de tout premier ordre en ce qui concerne les eaux d'infiltration.

D'autre part, l'action des eaux météoriques sur les roches ignées est très limitée, bien qu'elle soit accrue par l'anhydride carbonique qu'elles contiennent. L'eau de ces roches est, par conséquent, souvent peu chargée de substances dissoutes et ne contient que des quantités réduites de calcium, magnésium, sodium et potassium sous forme de bicarbonates, sulfates et chlorures.

Les terrains sédimentaires seront de beaucoup plus intéressants à notre point de vue, du fait de leur plus grande fréquence en surface, et aussi de leur plus grande possibilité d'attaque par les eaux.

Les principaux sels des roches sédimentaires, qui peuvent être dissous en assez grandes quantités, sont le $CaCO_3$, le $CaSO_4$, le $MgCO_3$ et le NaCl [6][1].

Les eaux météoriques qui percolent dans le sol sont déjà chargées de CO_2 pris dans l'atmosphère, mais cette charge augmente du fait de l'oxydation des matières organiques des couches supérieures du sol. Ces eaux attaquent les carbonates, particulièrement le carbonate de calcium (et aussi de magnésium), et se chargent par conséquent de carbonate et de bicarbonate de chaux (et de magnésium).

Il arrive aussi que les eaux dissolvent certaines quantités de $CaSO_4$ dont l'origine se trouve dans les formations de gypse, mais aussi dans les sulfures (pyrites) que contiennent certaines roches.

Mais le sel qu'on rencontre le plus fréquemment dans les eaux souterraines est certainement le NaCl, de très grande solubilité. Ce chlorure peut provenir des infiltrations des eaux marines, mais le plus souvent des roches sédimentaires elles-mêmes et des eaux qui les imprègnent quand ces roches n'ont pas encore subi de "lessivage" important. Nous reviendrons sur ces divers points dans l'étude de la concentration des eaux souterraines par dissolution.

Les concentrations des eaux qui percolent dans le sol et qui s'y chargent de matières dissoutes, en rejoignant les eaux souterraines ou en cheminant avec celles-ci, peuvent être augmentées soit par évaporation, soit par des dissolutions nouvelles. Ces deux processus en relation avec l'hydrologie des eaux souterraines entrent dans le cadre de cette étude.

CONCENTRATION DES EAUX SOUTERRAINES PAR ÉVAPORATION

Ce mode de concentration est à prendre particulièrement en considération dans les zones arides.

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[1] Les chiffres entre crochets renvoient à la bibliographie, p. 35.

L'évaporation peut tout d'abord agir dans la région d'alimentation: les premières pluies imprègnent les couches supérieures en y dissolvant certaines substances, mais leur eau est en grande partie reprise par l'évaporation avant qu'elles ne percolent profondément. De ce fait, ces eaux se concentrent fortement. Les pluies successives voient leurs eaux qui peuvent percoler s'enrichir en sels de la même façon, tout en permettant des infiltrations de plus en plus profondes.

Nous croyons cependant que la concentration par évaporation se produit le plus souvent dans les régions situées en contrebas des zones d'alimentation, à condition que les nappes y soient relativement proches de la surface. L'ascension capillaire et l'absorption de l'eau par la végétation y concentrent rapidement les eaux et peuvent provoquer des dépôts de sels dans la zone des racines et en surface.

Schoeller [18] donne un bel exemple d'une telle concentration pour la nappe de l'oued el Fakka en Tunisie. Cette nappe est surtout alimentée par les infiltrations de l'oued en question. Le résidu sec dans la zone d'infiltration y est inférieur à 2 000 mg/l. L'écoulement vers l'ouest amène une première concentration par dissolution, la nappe se trouvant à plus de 2 mètres sous le sol, ce qui rend difficile toute évaporation par capillarité; du fait de cette dissolution, le résidu sec croît jusqu'à 5 000 mg/l. Mais plus à l'aval, dans la zone où cette nappe est drainée par l'oued en Naggada, le résidu sec augmente très rapidement et peut atteindre 42 630 mg/l: cet accroissement est le seul fait de l'évaporation car l'eau se trouve dans cette zone de drainage à beaucoup moins de 2 mètres de profondeur. Schoeller montre également que cette évaporation a pour conséquence un enrichissement marqué en NaCl du fait de la précipitation du $CaSO_4$ et du Na_2SO_4.

Le phénomène décrit dans les paragraphes ci-dessus est d'autant plus intense, du point de vue de l'accroissement de la salinité, que les pluies sont moins fréquentes et que les conditions du climat favorisent l'évaporation (températures élevées et déficit de saturation de l'air). D'où, quand on passe des zones tempérées aux zones tropicales, augmentation de concentration suivie d'une réduction vers la zone équatoriale.

Nous avons envisagé jusqu'ici des actions permanentes. Mais des concentrations temporaires, accidentelles ou dues aux travaux de l'homme, peuvent également se produire du fait de l'évaporation. Tout ce qui provoque un relèvement d'une nappe aquifère quelque peu chargée favorise cette concentration et il peut en être ainsi dans la vallée basse d'un cours d'eau soumis à une crue d'une certaine importance ou dans le cas de l'établissement d'un barrage relevant le niveau du cours d'eau et la nappe qui s'y raccorde.

A titre d'exemple, citons le cas suivant: des crues dans la Californie du Sud en janvier 1916 provoquèrent la montée de la nappe dans les vallées basses environnantes, amenant des concentrations salines dans les couches supérieures après évaporation [10]. On cite aussi le cas de la Pecos Valley [8].

Quant à la nature des dépôts se produisant dans ces conditions, les premières précipitations dans le sol sont celles de $CaCO_3$ (tuf des régions autour des déserts), puis viennent celles de $CaSO_4$ (dans les régions désertiques) et enfin celles des sels de soude, carbonates ou sulfates.

On voit par conséquent que, si une augmentation des précipitations et par suite de l'écoulement entraîne en général une réduction de la concentration, la règle n'est pas absolue et qu'il peut y correspondre localement une augmentation de la teneur en matières dissoutes des eaux souterraines. De même l'étude de l'influence des travaux (barrages, coupures, dérivations, calibrage, etc., des cours d'eau) doit ne pas se limiter au point de vue strictement hydraulique (relèvement ou abaissement du niveau des eaux de surface et par suite souterraines), mais porter également sur les modifications des teneurs en matières dissoutes qui peuvent en résulter.

Nous allons envisager maintenant l'action générale des fluctuations climatologiques et de certains travaux de l'homme sur les concentrations des eaux des cours d'eau.

Les périodes sèches se caractérisent en général par des concentrations plus fortes provenant d'un côté de la part accrue des eaux souterraines, plus chargées, dans la décharge totale des rivières, et d'un autre côté, de l'accroissement de l'évaporation. Le tableau 1 illustre ces affirmations.

TABLEAU 1.

Date	Débit[1]	Matières dissoutes
		g/l
Colorado à Lees Ferry, Arizona [12]		
21–28 février 1953 (débit maximum)	118,8	0,967
11–20 juin 1953 (débit minimum)	1 365,3	0,277
Colorado près de Grand Canyon, Arizona [12]		
21–30 septembre 1953 (débit maximum)	91,0	1,310
11–20 juin 1953 (débit minimum)	1 322,0	0,338
Grand River près de Wakpala, Dakota-Sud [12]		
20–30 novembre 1953 (débit maximum)	0,1	2,740
22–24 mars 1953 (débit minimum)	28,1	0,198

[1] En millions de mètres cubes.

Les comparaisons peuvent aussi porter sur des années différentes. Ainsi, la Virgin River (affluent du Colorado) eut en 1953 une décharge annuelle deux fois moindre que celle de 1952 et il en résulta une concentration en matières dissoutes double de celle de 1952 [12].

Le U.S. Geological Survey a pu établir pour certaines rivières des diagrammes donnant la relation entre la salinité totale et le débit de la rivière. Le premier diagramme (voir fig. 1), par exemple, donne une telle relation pour le Colorado à Glenwood Springs. Quant au second diagramme (voir fig. 2), il est emprunté au *Water supply paper 1416* du U.S. Geological Survey [14].

Ce qui précède permet de se rendre compte de l'influence de l'irrigation sur la salinité des eaux en zones aride et semi-aride. Elle provoque évidemment une augmentation considérable de l'évaporation et de l'évapotranspiration, avec pour conséquence, comme on l'a signalé, une augmentation de la concentration.

Hook [8] estime que, dans la plupart des régions irriguées, la concentration moyenne des eaux du sol est au moins trois fois plus élevée que celle des eaux d'irrigation et que ce rapport atteint, dans certaines régions, des valeurs supérieures à 10. Ce rapport dépend de multiples conditions en dehors de la salinité des eaux d'irrigation: salinité propre du sol, perméabilité du terrain, drainage, état des cultures, conditions climatiques, lessivage par la pluie ou par des irrigations spéciales pendant la période sans végétation, teneur du sol en eau. En général, si la salinité du sol (zone des racines) est de 1 quand le sol est saturé d'eau, elle atteint 2 quand le sol est au point de ressuyage et 4 quand il est au point de flétrissement. L'importance considérable du drainage des régions irriguées tient non seulement à ce que les eaux drainées échappent à l'évaporation et peuvent donc souvent réintervenir dans le cycle de nouvelles irrigations (*return flow*), mais surtout à ce que ce drainage empêche ce qu'on a appelé les *salt troubles*. En effet, sans drainage, l'irrigation amène artificiellement la nappe au voisinage du sol, ce qui accroît considérablement l'évaporation (voir plus haut), laquelle entraîne à son tour une plus grande concentration des substances dissoutes. Celle-ci peut devenir nocive pour les plantes et même pour l'homme.

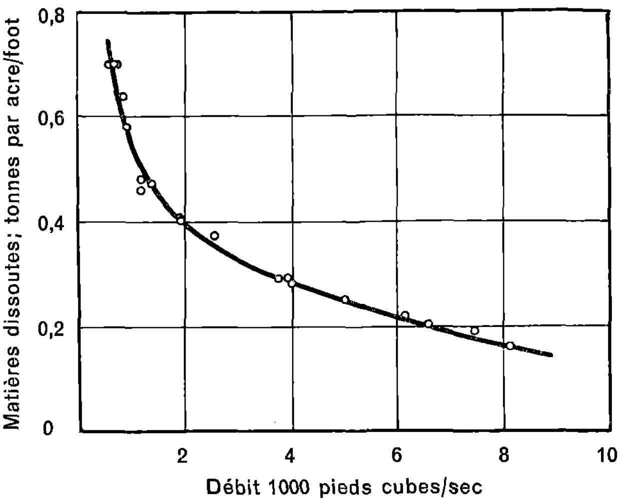

FIG. 1. Relation entre la salinité totale et le débit du Colorado à Glenwood Springs.

Aux États-Unis, les États de l'Ouest fournissent de nombreux exemples de l'influence de l'irrigation sur l'accroissement de la salinité [8].

Ainsi la Sevier River (bassin fermé) accuse en 1953 un accroissement considérable en matières dissoutes par rapport aux années précédentes, du fait de l'accroissement des irrigations (l'accroissement de la teneur en sodium fut particulièrement élevé).

Le tableau 2, emprunté à Hook [8], a été établi par le National Resources Committee (*Regional planning,*

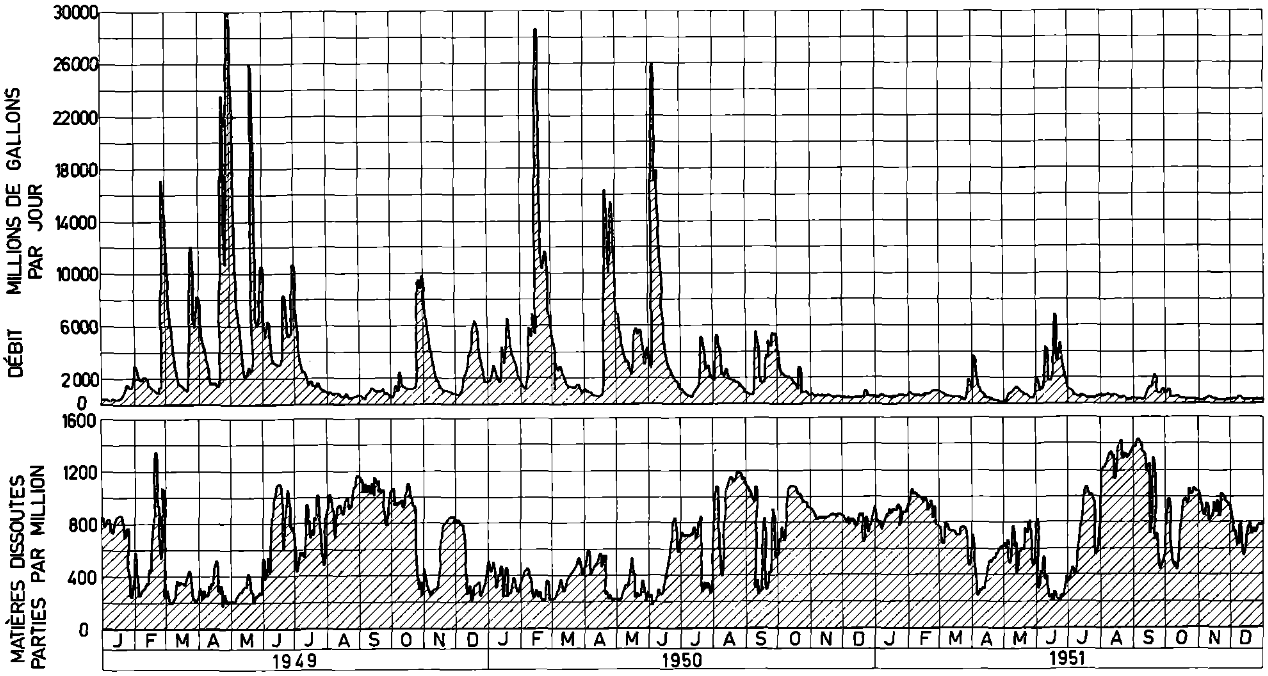

FIG. 2. Relation entre la quantité de matières dissoutes et le débit du Brazos River, Richmond, Fort Bend County, Texas.

Tableau 2.

Rivière ou drain	Concentration moyenne	Constituants					
		Ca	Mg	Na	HCO_3	SO_4	Cl
	kg/m³	%	%	%	%	%	%
Rio Grande à El Paso	*0,989*	*35*	*12*	*53*	*26*	*43*	*31*
Drains (en amont de Fabens)							
Playa	1,711	31	13	56	20	29	31
Franklin	2,173	29	13	58	17	28	55
Middle	2,514	30	10	60	14	29	57
River	3,105	32	10	58	13	27	60
Quadrilla	1,314	28	11	61	23	42	35
Mesa	2,603	27	10	63	16	36	48
Fabens	2,141	36	13	51	17	34	49
Moyenne d'ensemble	2,554						
Drains (Island et Tornillo)							
Fabens	2,027	36	12	52	16	30	54
Island	5,035	31	8	61	7	17	76
Border	6,689	27	7	66	5	19	76
Alamo	2,919	30	11	59	12	30	58
Tornillo	3,722	32	9	59	9	22	69
Moyenne d'ensemble	3,722						
Division El Paso, moyenne d'ensemble	3,016						
Rio Grande à Fort-Quitman	*2,230*	*26*	*11*	*63*	*12*	*29*	*59*

part VI, vol. I, Washington, 1938). Ce tableau montre l'accroissement considérable de la teneur en matières dissoutes du Rio Grande (moyennes de la période 1930–1936) entre El Paso (première ligne) et Fort-Quitman (dernière ligne). Les lignes intermédiaires se rapportent aux eaux des drains récoltant les eaux d'irrigation utilisées dans la vallée entre El Paso et Fort-Quitman.

Influence des réservoirs

Lorsqu'un bassin est aménagé à l'aide d'un ensemble de barrages-réservoirs, la régulation des débits qui en résulte conduit également à une régulation des quantités des substances dissoutes.

Cette dernière régulation peut être des plus intéressantes pour l'utilisation de l'eau, et notamment pour l'irrigation. En effet, les hautes concentrations correspondant aux faibles débits des cours d'eau pourraient en interdire l'usage en périodes sèches. Les réservoirs ont pour effet de ramener à une moyenne acceptable les teneurs fluctuantes selon la saison. Un bel exemple est donné par le Colorado en aval du Hoover Dam, après uniformisation quasi complète des teneurs en matières dissoutes par le Lake Mead.

A Lees Ferry, très en *amont* du Hoover Dam [12], la teneur du Colorado en matières dissoutes a varié en 1952–1953 de 0,319 g/l à 1,210 g/l. Immédiatement en aval du Hoover Dam, cette variation n'a été que de 0,477 g/l à 0,700 g/l. Des exemples de ce genre fourmillent dans les données relatives à l'Ouest américain [12].

Nous nous sommes assez longuement étendus sur les teneurs des eaux de rivières et l'on pourrait nous reprocher, comme nous l'avons dit en commençant, de sortir de notre sujet. Nous ne le croyons pas, car la salinité des eaux de surface est fortement influencée par celle des eaux souterraines, et l'étude des concentrations des eaux de rivière fournit un moyen de prendre une vue générale de la salinité des eaux souterraines et des sols du bassin.

Peut-être est-il intéressant à ce point de vue de signaler l'enquête entreprise par l'Association internationale d'hydrologie scientifique pour recueillir des indications sur les teneurs en matières dissoutes des grandes rivières du globe. Rares sont les pays qui disposent de données à cet égard et l'enquête en question ne progresse qu'avec difficulté.

CONCENTRATION DES EAUX SOUTERRAINES PAR DISSOLUTION

En fait, il est difficile de séparer l'influence de l'évaporation et celle de la dissolution. Il est certain qu'en ce qui concerne les phénomènes évoqués ci-dessus, l'évaporation n'est *pas seule* en cause: disons plutôt qu'elle joue le rôle principal. Nous envisagerons maintenant les phénomènes dans lesquels ce rôle revient à la dissolution.

Composition des nappes portées par des formations géologiques ne permettant aucune communication entre elles

Influence du gisement. Il s'agit de nappes bien distinctes. Ce que nous avons dit en commençant, au sujet de la cause initiale de la salinité des nappes, cause qui est toujours un phénomène de dissolution ou d'attaque chimique, indique que la composition de chaque nappe sera toujours plus ou moins influencée par la nature des roches qui la portent.

Deux nappes distinctes mais portées par des formations géologiques de même nature (calcaire, gréseuse, marneuse, etc.) auront de ce fait des compositions qui présenteront des caractères communs. Ceux-ci seront en général plus marqués si les terrains porteurs sont non seulement de même nature, mais aussi de même âge et plus voisins l'un de l'autre: on se rend compte en effet que ces deux dernières conditions tendent à rapprocher les conditions qui agissent sur la composition des eaux.

Influence des conditions "hydrologiques". Ce qui vient d'être dit au sujet de la communauté de caractères de deux nappes différentes ne concerne que l'influence des couches porteuses, c'est-à-dire de ce que nous avons appelé *le gisement.*

Mais d'autres facteurs interviennent, facteurs qui sont tous liés, dans une plus ou moins grande mesure, au mouvement des nappes et à leurs relations avec l'eau extérieure, ce qui nous a amenés à les qualifier de facteurs "hydrologiques".

Toute nappe est en effet alimentée soit par les précipitations, soit par des eaux superficielles, soit encore par d'autres eaux souterraines. Le caractère des eaux d'une nappe porte naturellement l'empreinte de l'histoire de ces eaux, de la composition des eaux superficielles qui les alimentent, de la nature des terrains traversés avant l'arrivée à la couche porteuse actuelle, de l'influence que l'évaporation ou les mélanges ont pu exercer sur elles. Deux nappes dans des couches porteuses identiques présenteront donc des caractères différents si elles ont eu une histoire hydrologique différente avant d'arriver à ces couches porteuses.

D'autre part, l'écoulement dans ces deux couches porteuses, identiques du point de vue pétrographique, sera conditionné par les dimensions des couches, par leur perméabilité, laquelle peut varier considérablement dans une même roche, par la répartition de cette perméabilité qui amènera la formation de zones d'écoulement privilégiées au voisinage de l'une ou de l'autre couche voisine, par les hauteurs piézométriques créant le mouvement, etc. Il en résultera des vitesses différentes et par conséquent des temps de contact plus ou moins longs avec les roches de la couche porteuse, des contacts différents avec les roches des couches voisines, des possibilités différentes d'évaporation et d'évapotranspiration, etc. L'homme pourra intervenir sur ces écoulements par des captages et des pompages, et toutes ces actions aboutiront nécessairement à rendra bien différentes les compositions de deux nappes dans des couches porteuses de nature identique.

Évolution de la composition des eaux d'une même nappe

Certaines des considérations rapidement énoncées ci-dessus montrent déjà que la composition des eaux d'une même nappe peut subir des modifications considérables sous l'action des facteurs que nous avons appelés hydrologiques.

Nous allons reprendre certaines de ces considérations, en les développant. On a vu que les eaux météoriques pénétrant dans des sols autres que les terrains siliceux ou silicatés se saturent rapidement en carbonate et en bicarbonate de chaux. Il en résulte que, dans une nappe qui se charge de plus en plus de matières dissoutes (soit dans le temps, par un contact de plus en plus prolongé avec un même sol, soit surtout dans l'espace le long d'un trajet d'amont vers l'aval), le rapport des ions SO_4 et des ions Cl aux ions CO_3 ira en augmentant, puisque l'eau peut encore dissoudre des sulfates et des chlorures mais non plus des carbonates. La concentration continuant, l'eau ne pourra plus dissoudre de sulfates, dont le maximum sera à son tour atteint, et c'est alors le rapport des *ions* Cl *aux ions* SO_4 *et aux ions* CO_3 qui augmentera.

Pour les mêmes raisons, le rapport de Mg à Ca et ensuite celui de Na à Mg et à Ca iront en augmentant (Schoeller [19]).

Delecourt [4] énonce des considérations analogues et montre que les eaux pénétrant dans le sol sont d'abord en général franchement dures du fait de la dissolution du carbonate de chaux, mais qu'après un cheminement plus ou moins long dans la nappe, elles deviennent assez brusquement moins dures, en se chargeant de sels alcalins et surtout de sodium. Delecourt en conclut que, dans une zone intermédiaire, il y a échange de bases et addition de chlorures et il s'est attaché à rechercher ce qu'il a appelé la "limite de salure" séparant la première zone (à laquelle il donne le nom de "zone dessalée" avec une dureté supérieure à 6° français) d'une deuxième zone, dite "à eaux salées", avec une dureté inférieure à 6°. Contentons-nous d'ajouter que, pour la première zone, le résidu à 100° est inférieur à 0,5 g/l et qu'il est compris entre 0,5 et 3 g/l pour la seconde.

Si l'on s'éloigne encore de la zone d'alimentation, les eaux redeviennent dures, mais leur concentration dépasse 3 g/l; c'est la troisième zone, dite de "sursalure", où la dureté est due à la présence de sulfates de chaux et de magnésie ainsi que de chlorure de magnésie.

En résumé, on trouve donc en partant de la zone d'alimentation et en suivant le sens de l'écoulement: *a*) une zone dessalée (ce nom provenant de ce que le lessivage continu auquel est soumise cette zone par les eaux en provenance de la zone d'infiltration y a enlevé une bonne partie des sels des eaux et des roches portant la nappe); *b*) une zone d'échange de bases séparant la première de *c*) la zone de salure, elle-même suivie de *d*) la zone de sursalure.

Il s'agit évidemment là du cas d'une nappe ne recevant pas d'apports qui pourraient modifier sa composition.

Ces modifications dans la composition des eaux d'une nappe sont évidemment influencées par la vitesse de l'écoulement et par la longueur du trajet: ainsi, le lessivage étendra ses effets plus loin vers l'aval si le courant de la nappe est relativement intense et rapide.

Nous donnerons tout d'abord des exemples de semblables influences dans des nappes de régions non arides que nous avons pu étudier plus longuement, mais nous montrerons cependant des cas d'application de ces principes en zones aride ou semi-aride.

La carte (fig. 3) reproduit, d'après Delecourt, les tracés des limites de salinité pour diverses nappes artésiennes du nord de la Belgique. L'examen de la limite de salinité de la nappe qu'on a appelée le Grand Courant (dans le Crétacé) révèle notamment deux refoulements très marqués de cette limite vers le nord, entre Bruxelles et Louvain d'abord, et surtout dans le Limbourg ensuite.

Nous avons rapproché cette carte de celle qui indique l'étendue et les épaisseurs du Crétacé en Belgique (fig. 4) d'après Legrand.

La ligne O marque l'origine de ces couches et l'on voit que toute la partie centrale du pays est dépourvue de Crétacé. On constate également que les deux refoulements vers le nord de la limite de salinité du Grand Courant, branche supérieure, correspondent précisément à deux extensions vers le sud du massif crétacique du nord du pays. Cette extension est particulièrement marquée au sud du Limbourg où le Crétacé affleure (sous une faible épaisseur de Quaternaire) sur toute la Hesbaye. Cette vaste étendue de réception, à une cote relativement élevée pour la région qui nous occupe, et la grande perméabilité du Maastrichtien (sommet du Crétacé) ainsi que d'une partie du Heersien (Éocène inférieur), doivent donner des valeurs assez élevées au débit du Grand Courant supérieur dans cette région. Il a dû en résulter un "lessivage" important des couches considérées avec, comme conséquence, une extension marquée de la zone dessalée vers le nord, dans le sens du mouvement.

On se rappellera que la limite de salinité est caractérisée par une dureté de 6° français, des duretés supérieures marquant l'amont (sud dans l'exemple cité), alors que l'aval montre des duretés inférieures à 6° français. On constate cependant autour de cette limite de salinité certaines anomalies. De plus, les eaux de certains puits y montrent des diminutions de dureté dans le temps. Ainsi, deux puits voisins de 440 mètres donnent lieu aux observations suivantes:

Puits I, creusé en 1949: dureté à cette époque, 12,4° français; dureté en 1956, 5,6° français (ce puits s'enfonce de 23 mètres dans le Maastrichtien-Crétacé supérieur sans le traverser).

Puits II, creusé en 1956: dureté en 1956, 5,6° français (ce puits traverse le Maastrichtien et pénètre même sous cette couche de 13 mètres dans le Sénonien).

Comment expliquer la variation de dureté du puits I?

Disons d'abord que le tuffeau du Maastrichtien est beaucoup plus perméable que la craie du Sénonien. Il en résulte que l'écoulement dans le Maastrichtien se fait plus rapidement que dans la couche sous-jacente. Conformément à ce qui a été dit précédemment, le lessivage du Maastrichtien est plus poussé et s'étend plus vers l'aval que dans le Sénonien (fig. 5).

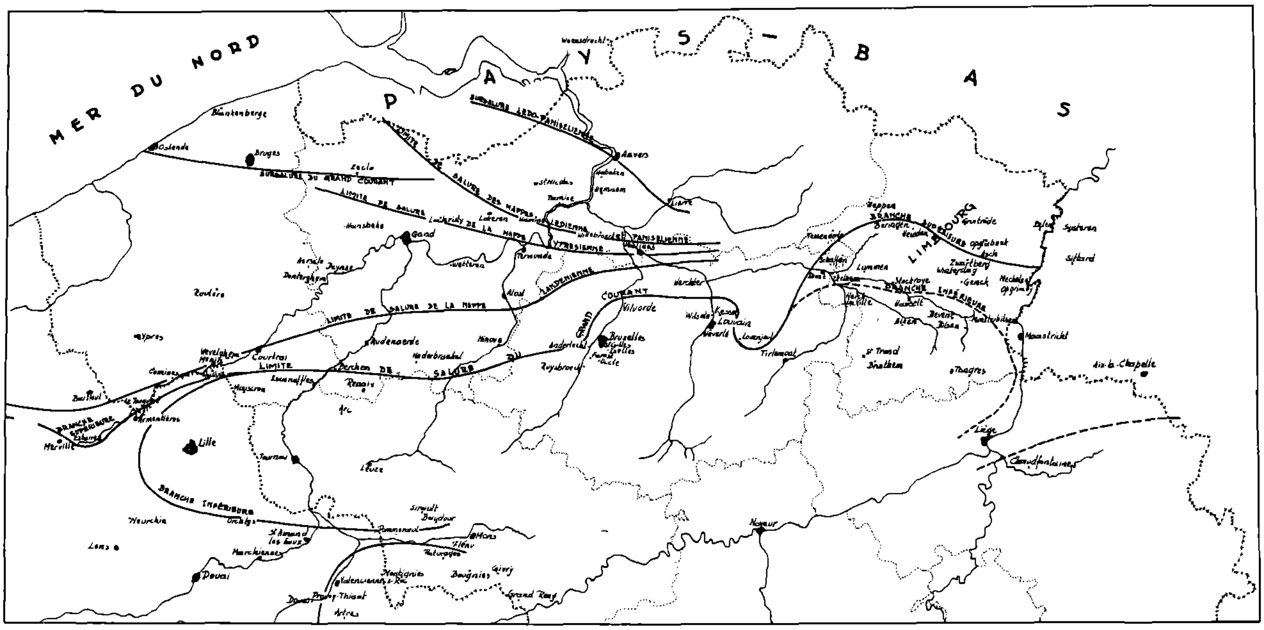

FIG. 3. Carte des limites de salinité dans les nappes artésiennes du nord de la Belgique.

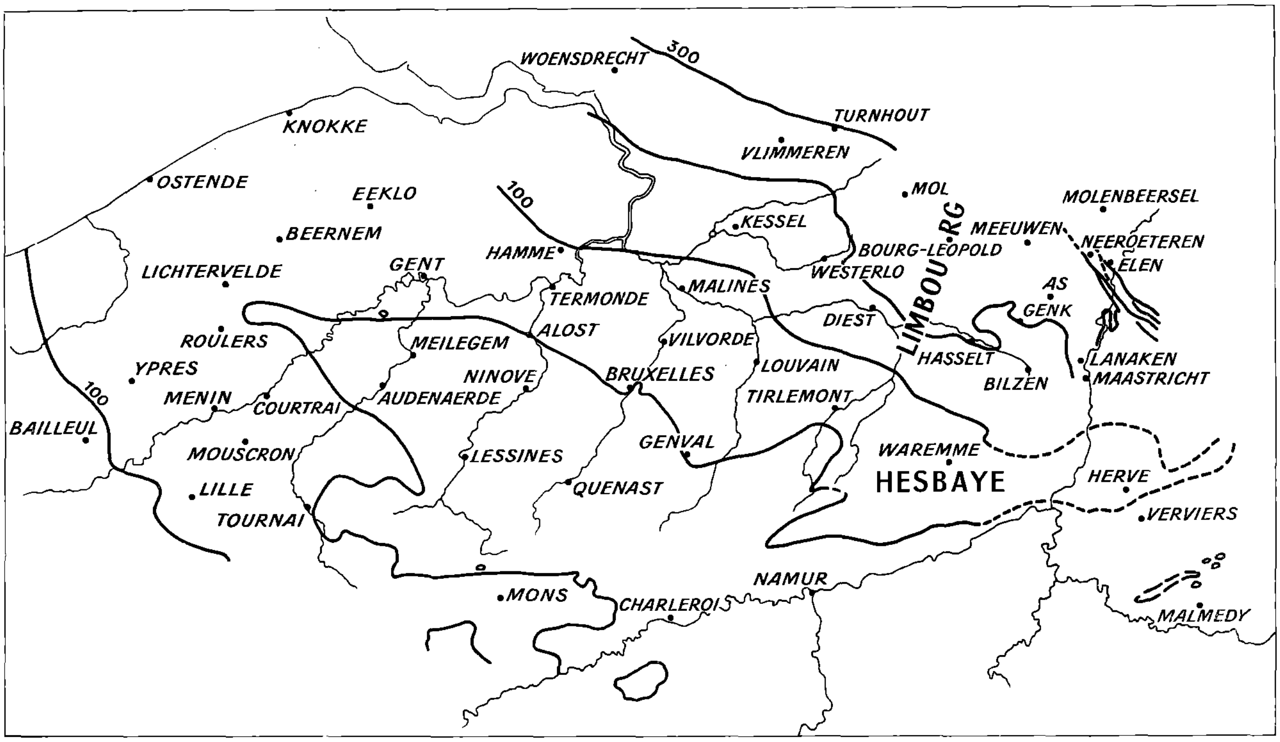

FIG. 4. Carte donnant l'étendue et les épaisseurs du Crétacé en Belgique.

Le premier puits n'atteignant pas le Sénonien fut donc alimenté en 1949 uniquement par de l'eau du Maastrichtien dont le lessivage fait ici une région déjà quelque peu dessalée et présentant donc une certaine dureté (12,4° français).

Mais la continuation des pompages au cours des années attirera petit à petit vers le puits des eaux de la couche sénonienne sous-jacente, moins perméable et par conséquent moins dessalée. L'arrivée de cette eau fera tomber graduellement la dureté de l'eau du puits qui s'établira en 1956 à 5,6° français, tout comme celle du puits II qui, pénétrant dans le Sénonien, reçoit immédiatement un mélange des eaux des deux couches et donne dès le début des eaux à 5,6° français.

Il est vraisemblable d'ailleurs que ce titre baissera encore, car avec le temps, la part des eaux venant du Sénonien augmentera encore. La figure 5 montre en effet qu'au début, dans le puits I, toute l'eau venait de la couche supérieure (k_1), mais qu'avec le temps, l'eau arrivant au puits par la trajectoire $\alpha\beta$ proviendra de la couche inférieure plus salée. Plus tard encore, quand le liquide qui se trouvait en δ, à l'origine du pompage, arrivera au puits, il sera suivi de liquide provenant d'au-delà de δ sur la trajectoire $\delta\varepsilon$, et qui sera plus salé. Les trajectoires arrivant au puits, qui y amenaient toutes au début de l'eau de la couche k_1, y amèneront l'une après l'autre de l'eau plus salée venant de k_2, un certain nombre de trajectoires (les supérieures) y amenant cependant toujours de l'eau de k_1.

Ces considérations peuvent d'ailleurs donner lieu à des calculs assez précis fondés sur le tracé des lignes de courant et des lignes équipotentielles dans deux couches perméables superposées, de perméabilités différentes [24].

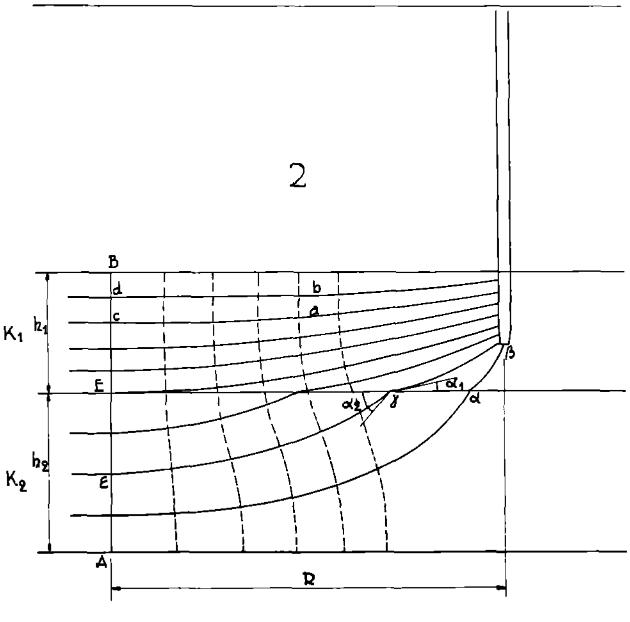

FIG. 5. Alimentation, variable en qualité, d'un puits prenant ses eaux dans des couches superposées de perméabilités différentes.

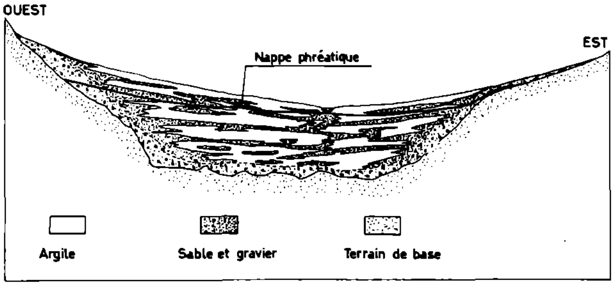

FIG. 6. Coupe transversale de la vallée basse du Douglas Basin dans l'Arizona.

Un de nos collaborateurs [20] a réalisé en laboratoire une maquette reproduisant, sans prétention d'échelle, pareil phénomène, en colorant l'eau salée pour en détecter plus aisément l'apparition.

Nous avons quelque peu insisté sur le phénomène car, à notre avis, il se répète très souvent lors des pompages intensifs auxquels on procède pour se procurer l'eau d'irrigation en zones aride et semi-aride. Nous n'en exposerons rapidement qu'un exemple tiré d'une étude de l'U.S. Geological Survey. Il s'agit du Douglas Basin dans l'Arizona. La vallée basse est constituée de dépôts, atteignant jusqu'à 850 mètres d'épaisseur et d'âge surtout quaternaire. Ces dépôts comprennent des alternances de couches perméables irrégulières séparées par des dépôts argileux et vaseux (fig. 6). Un ensemble de puits captent leur eau dans ces couches et les pompages qui retiraient 21 millions de mètres cubes d'eau en 1947 sont successivement passés à un total de 47 millions de mètres cubes en 1951. Un certain puits d'observation, le (D-23-27) 19 d a d, présente une eau dont les caractéristiques se sont modifiées considérablement de 1946 à 1951, suivant les données du tableau 3.

L'augmentation en matières dissoutes – surtout en Na et en Cl – est réellement considérable. Ce puits d'observation se trouve à proximité de pompages dont l'importance s'est accrue dans de très fortes proportions au cours des six années considérées.

L'interprétation nous paraît des plus aisées: au début, le puits donnait la composition de l'eau de la couche perméable où il aboutissait. Les pompages, et surtout les pompages accrus, ont appelé, non seulement l'eau de la couche bien perméable, mais aussi, avec le temps, celle des couches moins perméables plus salines (voir Schoeller [19] au sujet de l'influence de la finesse des sédiments sur la teneur de leur eau en sels). La salinité des eaux pompées s'est donc accrue avec le temps, la proportion des eaux d'origine salée augmentant sans cesse, comme dans l'exemple traité longuement ci-dessus.

Il a été signalé qu'une des causes de la salinité de certaines eaux était l'intrusion des eaux marines dans les nappes aquifères bordant les océans. Toutefois, cette pénétration peut également s'effectuer à partir de cours d'eau où les saux salées de la mer pénètrent comme nous l'exposerons ci-après et même à partir de cours d'eau et de lacs dont la salinité a été considérablement augmentée par l'évaporation et l'évapotranspiration de leurs bassins et par les irrigations.

Avant de passer à l'étude de l'influence des eaux souterraines par les eaux salées de la mer et des cours d'eau, il paraît nécessaire de dire quelques mots de la façon dont l'eau de la mer peut s'avancer dans les cours d'eau. Cette question constitue plutôt un problème d'hydraulique qui a été considérablement approfondi au cours des dernières années sous la rubrique des courants de densité, tant à l'aide d'études hydrodynamiques que par des essais sur modèles. Il ne peut être question d'indiquer ici tous les développements de ce problème. On pourra se reporter aux études spécialisées [23].

Disons cependant que, d'une façon générale, l'eau de la mer peut se comporter de trois façons différentes dans le cours inférieur des cours d'eau qui y débouchent.

S'il y a peu ou pas de marée, l'eau saline se propage à marée montante sous forme d'une "langue" (*wedge*) sur le fond du cours d'eau sans guère se mélanger avec l'eau douce amenée par le fleuve. Cette langue saline prend une forme d'équilibre qui varie avec le débit d'amont, refoulée vers la mer aux forts débits, et pénétrant dans les terres aux débits d'étiage (fig. 7). C'est le cas des cours d'eau de la Méditerranée (Rhône) et du golfe du Mexique (Mississippi). Des courants de ce genre peuvent aussi se produire aux écluses faisant communiquer des canaux de navigation ou d'irrigation avec des fleuves à marée à eau salée ou avec la mer.

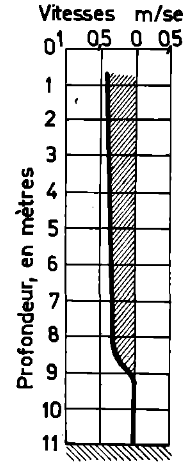

FIG. 7. Répartition des vitesses dans l'embouchure du Rhône (d'après Danel, Congrès de navigation de Rome, 1953).

TABLEAU 3. Teneur en grammes par litre

Date	SiO_2	Ca	Mg	Na+K	HCO_3	SO_4	Cl	F	NO_3	Total des matières dissoutes
5 février 1946		0,180	0,093	0,429	0,261	0,484	0,740	0,006	0,0004	2,060
16 octobre 1951					0,270		1,060	0,0008		
28 mai 1952	0,026	0,380	0,212	0,966	0,249	1,140	1,790	0,001	0,0042	4,640

Certains dispositifs peuvent réduire les intrusions d'eau salée à travers ces écluses, mais leur étude est trop spécialisée pour être développée ici [11, 17, 21, 22, 23].

Lorsque les facteurs favorisant le mélange se développent (marées plus fortes, rugosité accentuée du lit), la langue saline se mélange de plus en plus avec l'eau douce et des couches de densités décroissantes se créent et se superposent. En même temps, la salinité décroît de l'aval vers l'amont. Il en résulte que les courbes isosalines dans le profil en long de la rivière sont des lignes relativement peu inclinées de l'aval vers l'amont. La masse saline avance d'ailleurs à chaque courant de flot pour reculer au cours du jusant suivant alors que la marée est insuffisante pour l'influencer dans le premier cas envisagé. D'autre part, bien que la marée ait pour effet d'inverser le sens du courant pendant le flot et le jusant sur toute la hauteur d'une section transversale, on constate cependant que, dans les couches supérieures, le débit net est dirigé vers l'aval, alors qu'il s'écoule vers l'amont dans la partie inférieure de la section. Cela conduit à ce qu'en fait l'estuaire se comporte comme s'il était constitué par deux couches non homogènes au point de vue de la salinité. Cette structure se reflète d'ailleurs sur la forme des courbes de salinité qui présente un point d'inflexion avec accroissement brusque vers la mi-hauteur (fig. 8). Le frottement de ces deux couches l'une sur l'autre provoque un transfert d'eau salée à la couche supérieure [15, 23]. Pritchard a également observé que, sous l'influence de la rotation de la terre, les concentrations salines dans une section droite d'un estuaire sont plus élevées vers la rive gauche que vers la rive droite (dans l'hémisphère nord).

Ce second type d'estuaire se rencontre notamment dans les fleuves des États-Unis se jetant dans l'Atlantique.

Lorsque les causes déjà signalées provoquent un mélange plus complet, les courbes de salinité de la figure 8 deviennent presque ou même absolument verticales. C'est le cas de la plupart des fleuves d'Europe occidentale. Pour ces rivières, la salinité décroît de l'aval vers l'amont suivant des lois qui ont pu être établies par A. B. Arons et H. Stommel [1] et quelque peu modifiées par L. J. Tison [23].

Des questions de salinité peuvent aussi se poser pour les mers intérieures et les lacs. C'est bien souvent l'évaporation qui provoque cette salinité, évaporation telle qu'elle transforme en vapeur tout le débit reçu par les lacs en question. De tels lacs salés se rencontrent donc particulièrement dans les régions arides. C'est le cas de la mer Morte en Israël, de la mer Caspienne et des grands lacs voisins, du Grand Lac Salé et des lacs du Great Basin des États-Unis, etc. Une littérature très abondante se rapporte à ce problème [7].

Le problème de la salinité des eaux de certains lacs se pose cependant parfois sous une autre forme. On constate par exemple que le Kivu, au Congo belge, et dans une zone qui est loin d'être aride, présente diverses particularités. C'est ainsi que, si la salinité n'est que de 1 g/l pour la couche supérieure, jusqu'à 50 ou 75 mètres, elle atteint près de 3,9 g/l dans les couches plus profondes. En outre, ces couches profondes contiennent des quantités considérables de gaz dissous (CO_2, méthane et H_2S). L'explication de cette constitution semble être la suivante: le lac est bordé, sur une bonne partie de son pourtour, par des terrains volcaniques dont certains sont très récents. La pénétration de la pluie dans ces terrains est si aisée qu'il ne se produit aucun écoulement superficiel. Les eaux s'infiltrent dans ces terrains récents, peu lessivés, s'y chargent fortement de matières minérales et débouchent dans le lac en profondeur. Ces eaux chargées ne peuvent participer au *turnover* habituel [2, 3, 5].

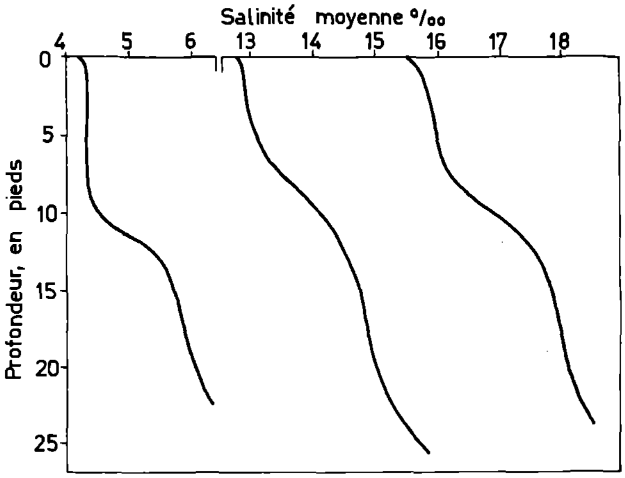

FIG. 8. Courbes de répartition de la salinité dans trois sections du James River (d'après Pritchard).

Si l'on revient aux intrusions de l'eau saline de la mer et des estuaires dans les terres, on constate que leur existence donne lieu à une situation assez typique provenant de la superposition des eaux douces météoriques et des eaux salées infiltrées (théorie de Ghyben-Herzberg).

Ces eaux ne se mélangent guère et les eaux douces (qui trouvent leur exutoire vers la mer) s'établissent à une hauteur *h* au-dessus du niveau de la mer. (Entre les eaux douces, il y a cependant une faible couche d'eau de mélange dont Huisman évalue l'épaisseur à une dizaine de mètres [9].) En supposant le phénomène statique, et en tenant compte du fait que la densité de l'eau de mer est égale à 1,026 fois environ celle de l'eau douce, la hauteur *h* de cette dernière provoque le refoulement de l'eau salée qui est chassée sur une hauteur H égale à environ 40 fois *h*: il faut en effet une colonne $H + h$ d'eau douce pour faire équilibre à une colonne H d'eau salée. C'est là l'explication du fait qu'au voisinage des mers bordées de formations perméables, les puits rencontrent de l'eau salée après avoir traversé une certaine épaisseur d'eau douce (fig. 9).

De telles constatations ont pu être faites, en particulier, sur les côtes des Pays-Bas, sur la côte du golfe du Mexique, en Australie, aux îles Hawaii, sur la côte américaine de l'Atlantique, en Californie, etc. Dans ces régions, l'équilibre réalisé par les siècles est troublé par les pom-

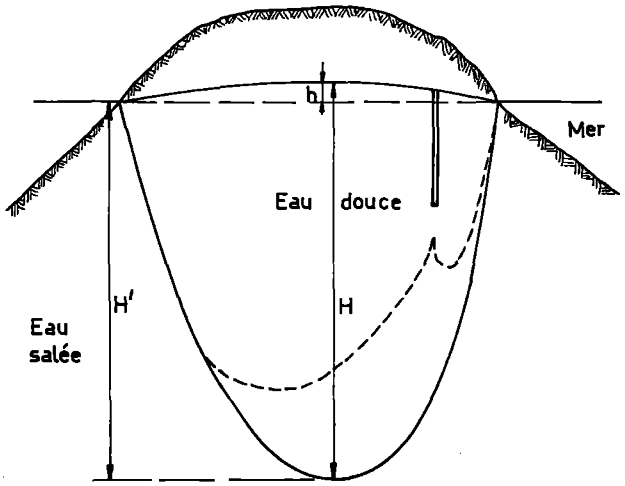

Fig. 9. Schéma de la superposition des eaux douces aux eaux salées marines, au voisinage de certaines côtes.

pages pour les distributions d'eau. Ces pompages réduisent *h* et il doit en résulter avec le temps une diminution de H, c'est-à-dire un relèvement du niveau des eaux salées. C'est ce que montre le schéma emprunté à Krul et se rapportant aux dunes qui servent à l'alimentation d'Amsterdam (fig. 10).

On remarquera cependant qu'il n'est pas question d'écrire une simple équation d'équilibre statique comme on l'a fait ci-dessous pour éclairer le principe du phénomène.

Un autre danger est d'ailleurs créé par les épuisements que nécessite à l'arrière des dunes, dans les polders dont le niveau est au-dessous du niveau moyen de la mer (parfois plusieurs mètres), l'évacuation des eaux de pluie et des eaux d'infiltration qui ne peuvent trouver d'exutoire naturel. Ces épuisements tendent à y attirer les eaux de la mer passant sous la lentille d'eau douce (fig. 10). On voit dans ces conditions tout l'intérêt qu'il y a à garder et même à renforcer la barrière d'eau douce créée par l'effet Ghyben-Herzberg. Nous disons renforcer, car on peut en effet alimenter la barrière formée par la nappe douce des dunes, ce qui a été fait notamment aux Pays-Bas. Cette recharge de la nappe peut d'ailleurs être effectuée au moyen d'eaux non épurées, simplement soumises à une grossière filtration pour éliminer tout ce qui pourrait empêcher leur percolation. Avec une recharge suffisante, la nappe d'eau douce peut alimenter des captages et en même temps servir de barrière.

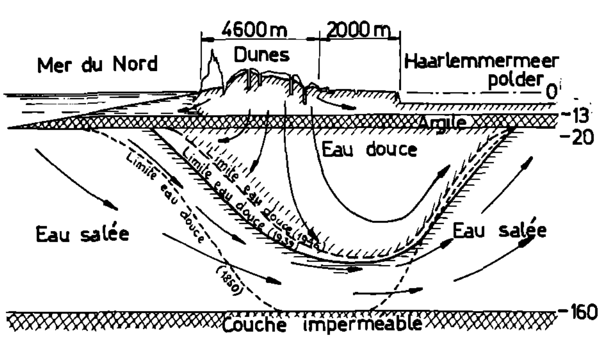

Fig. 10. Superposition des eaux douces aux eaux salées dans les dunes néerlandaises, sous l'action de pompages, d'après Krul.

La figure 10, dont il a déjà été question, montre le retrait général de l'eau douce sous l'action des pompages des dunes. En fait, chacun des puits, par suite du rabattement qu'il provoque dans son voisinage plus ou moins immédiat, provoque une montée de la nappe saline, d'autant plus forte que le rabattement est plus marqué (fig. 9). Il faut insister sur le fait que le nouvel équilibre qui s'établit par suite du pompage ne peut être déterminé par des considérations purement statiques, mais on ne pourrait procéder à une analyse exacte de la situation qui correspondrait à un rabattement donné que par la méthode graphique du tracé par éléments des lignes équipotentielles et des lignes de courant. Le problème a également été traité mathématiquement aux Pays-Bas.

L'analyse de telles pénétrations d'eaux salées est encore compliquée lorsque les couches porteuses présentent des perméabilités différentes. Dans ce cas, on doit étudier le problème en introduisant des considérations analogues à celles décrites ci-dessus (voir p. 30). Dans la nature, ces phénomènes peuvent être suivis à l'aide de mesures de la résistivité *in situ* (voir notamment [16] et [25]).

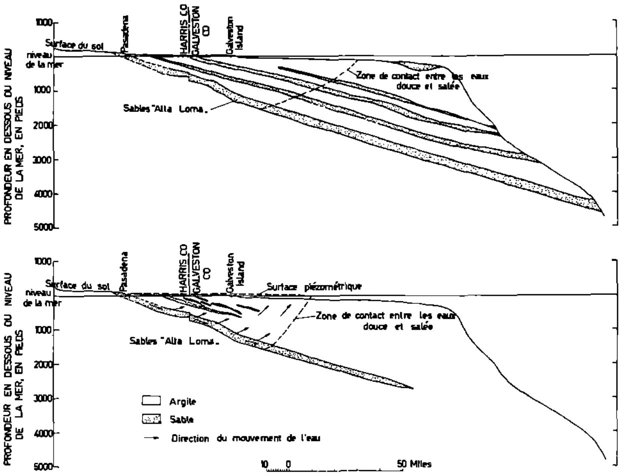

Fig. 11. Coupes représentant deux dispositions possibles de la nappe des "Alta Loma Sands".

La disposition de la figure 8 illustre le cas simple d'une nappe libre. Mais les conditions Ghyben-Herzberg peuvent aussi se rencontrer pour les nappes artésiennes. On les rencontre notamment dans certaines régions voisines du golfe du Mexique. Les deux coupes (fig. 11) sont empruntées à une étude du U.S. Geological Survey pour le Galveston County et représentent deux dispositions possibles de la nappe des "Alta Loma Sands". Dans le premier cas, correspondant à des argiles parfaitement imperméables, la disposition est analogue à celle de la figure 8, la limite entre les eaux douces et salines s'établissant suivant une surface discontinue.

Dans le second cas, compte tenu de ce que l'argile n'est jamais complètement imperméable, on observe encore une zone de contact entre les deux eaux, mais la décharge des eaux douces, au lieu de se faire au contact du sable et de la mer, s'effectue, à travers l'argile, vers la mer.

Une mention spéciale doit être réservée aux eaux des nappes alluviales en communication avec les eaux d'une rivière. En général, le comportement des eaux de ces nappes ne se distingue guère de celui des autres nappes phréatiques en temps d'étiage ou d'eaux moyennes, la nappe se déversant alors dans la rivière sans être guère influencée par elle.

En temps de crue, l'inverse se produit souvent et l'eau de la rivière alimente la nappe. L'eau de la rivière, surtout si elle est de provenance quelque peu lointaine, a une constitution chimique différente de celle de la nappe, et cette dernière en voit ses eaux chimiquement affectées, l'influence diminuant à mesure qu'on s'écarte de la rivière.

Un phénomène identique, mais cette fois permanent, peut être dû à la construction de barrages. De même des captages affectués à proximité d'une rivière peuvent provoquer une pénétration des eaux de cette dernière dans la nappe du fait du rabattement. Nöring [13] donne de multiples exemples intéressants de pareilles influences.

SUMMARY

Hydrology and salinity of ground-waters (L. J. Tison)

The author first considers the causes of the existence of, and particularly of modifications to, the dissolved matter in ground-water. He examines the effects of evaporation on water-levels near the surface, and also deals briefly with changes due to irrigation. He then goes on to speak of transformations occurring in depth, and this leads him to consider the case of a non-saline zone, a saline zone (separated from the first by the base exchange horizon) and, lastly, a hyper-saline zone. He then discourses on the factors influencing these modifications. From these, he deduces the differences which may exist between water-tables of different formations, between those of identical formations, and between bodies of water in the same water-table. Transformations due to human intervention, and particularly to pumping, are then described; the change in the composition of any particular water during pumping is dwelt on at some length. The author then devotes a whole section of his report to sea-water infiltration, the complex phenomena attributable to water-catchment in coastal areas, the ways in which salinization of this kind can be remedied, and certain special cases in the areas mentioned.

DISCUSSION

N. Ahmad. Dr. Tison has given a table showing the dissolved content of Colorado and Grand Rivers. The order seems to be very high as compared with the rivers in Pakistan. Is the dissolved content really so high?

L. J. Tison. Les chiffres en question ont été empruntés à la publication du Geological Survey, *Water Supply Paper 1380*, 1957 [12]. Les chiffres surprendront moins quand on se rappellera que la salinité a précisément été considérablement accrue par le retour des eaux de drainage des champs irrigués.

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CONDITIONS OF FORMATION OF FRESH WATERS UNDER PRESSURE IN CERTAIN DESERT ZONES OF NORTH AFRICA, THE USSR AND SOUTH-WEST ASIA

by
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Following investigations carried out in a number of countries, it has been established that at the limits of mountain regions bordering on deserts and semi-deserts immense artesian basins exist, in the strata of which circulate powerful currents of underground waters with varying mineralization and temperatures and water heads of several hundred metres above the surface. The mountain systems are not only regions of supply to water-bearing horizons, distributed along the borders of slopes and troughs, but they represent systems of water heads that determine the hydrodynamics of underground waters encountered when drilling holes in various spots in the basin. The speed of movement of ground-waters in water-bearing beds situated in artesian basins depends not only on the water-conducting properties of the rocks but also on the difference in ground-water heads, the supply regions of water-bearing strata, and the location of their artificial (drill-holes) or natural discharge.

So, for instance, in North Africa, in the Sahara, the position of water levels in deep water-bearing horizons depends on the difference in level between the well's mouth and the intake area in the Atlas mountains, which extend parallel to the Mediterranean and have an altitude of 2,000–2,500 m.

At the limits of this mountain system is to be found the supply of water-bearing horizons, enclosed in upper Cretaceous and Lower Cretaceous sediments. The yearly precipitation value in this region reaches up to 600 to 800 mm. Geological cross-sections from the Mediterranean Sea through the Atlas mountain range and the Northern Sahara, and also the cross-cuts of bore-holes at the limits of the Sahara, show that directly to the south of the pre-Saharian Atlas (near the town of Biskra), and to the north of In-Salah and Radamès, there is a vast syncline filled with a series of Lower Cretaceous, Upper Cretaceous, Tertiary and Quarternary sediments with a thickness of over 2,000 m. (see figures 1 and 2). This great tectonic structure covers an area up to 700,000 km.^{2}, and has to the north, west, and south Cretaceous rocks directly near the surface. Lower Cretaceous sediments, over 800 m. thick, are represented on the borders of the trough by sand-gravel rocks of good permeability. They easily absorb not only the atmospheric precipitations, but also the waters of superficial currents during high waters. As a result of the vast area of distribution of the Lower and Upper Cretaceous rocks and of the high infiltration value—which reaches 100 mm. a year—immense reserves of underground waters are constituted within the limits of the North African artesian basin and are used at present by a series of wells in North Africa. In Zelphane (Algeria) a well 1,167 m. deep gave a fountain with a head of 72 m. above the surface, and a yield at the surface of about 325 m.^{3}/hr. At the indicated depth of the well the temperature of underground water attains 42° C., and is mineralized to the extent of 0.5 gm./l. In Africa, isolated wells exist in which the water head is more than 100 m. above the earth's surface, and the elevation above sea-level at the well-head is about 350 m. While the mineralization of underground water in deep horizons is insignificant and varies from 0.3 to 0.5 gm./l., in the upper horizons mineralization already reaches 2–20 gm./l. This mineralization of ground-waters in the upper zones is related to continental salinization, gradually increasing from the mountain slopes to the depression and attaining a maximum value in its central part. In some regions, depending on the filtration properties in rocks and on the activity of water exchange, the mineralization of underground waters in deep water-bearing horizons changes along the bed with the transition from fresh water to brackish, according to the movement from the supply region to the discharge area. A detailed study on the underground waters of north-western Africa, including artesian waters, is being prepared by the great French specialist G. Drouhin.

Basins of underground waters under pressure analogous to that existing in north-western Africa are observed at present in the Libyan desert, in the territory of the United Arab Republic and in Saudi Arabia. In the territory of these countries the greatest part of underground

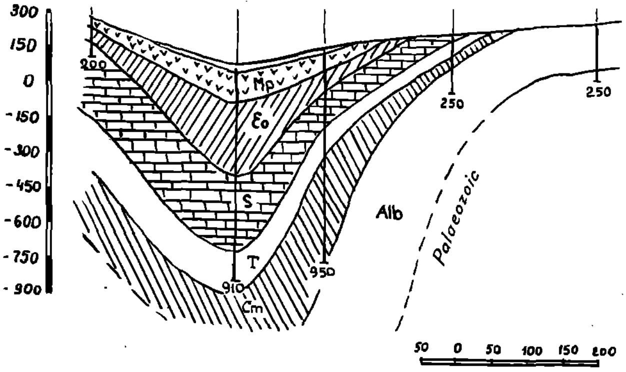

FIG. 1. Schematic geological crosscut along the line Biskra/In-Salah.

waters is included in powerful strata of Nubian Sandstones, that are equivalent to continental sediments of the Lower Cretaceous, from which bore-holes in Morocco, Algeria and Tunisia obtain water.

In the regions of Egypt ancient rocks are represented by crystalline, very crumpled schists, and by Precambrian volcanic lavas cut by granitic intrusions. Igneous rocks are covered by Nubian Sandstone, which in its turn is covered by the Upper Cretaceous and by clayey masses of the Danian Stage.

The Nubian Sandstone in Upper Egypt is up to 600 m. thick, sometimes even more, and if we include the Upper Cretaceous rocks it attains a thickness of more than a thousand metres.

The Upper Cretaceous rocks are covered by Tertiary rocks. Cretaceous and Tertiary sediments occur with a small gradient, from south-west to north-east, and form a monoclinal structure dipping into the Mediterranean Sea.

In some parts of Egypt, particularly in the region of the Suez Canal, outcrops may be observed which have the form of domes rising from the surface of Cretaceous rocks. These outcrops are complicated by faults. In the Sinai peninsula Tertiary sediments form a syncline structure, complicated by tectonic disturbances. These Tertiary sediments are represented by calcareous and marly rocks.

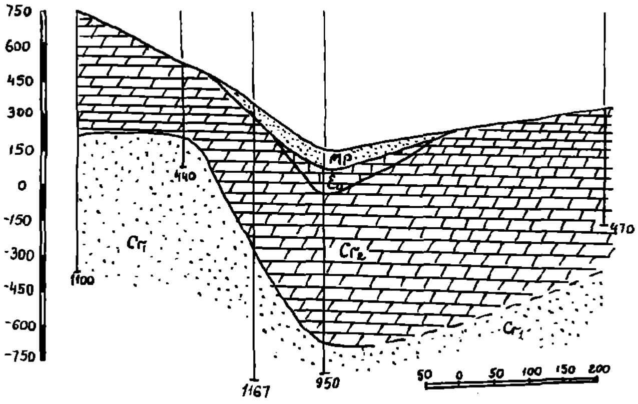

FIG. 2. Schematic geological crosscut along the line Laghouat/Fort Radamès.

Detailed hydrogeological descriptions exist for the Kharga and Dakhla oases; they were published by the Desert Institute of Egypt in 1954.

Because of the great importance of these data for any study of the hydrogeological characteristics of Egypt, we are giving a summary of them below.

The elevation above sea-level of the oases varies from 100 m. in the case of Kharga to some 150 m. in that of Dakhla, while the altitude of the plateau varies from 300–400 m.

The Kharga oasis is situated at a distance of 200 km. from the Nile valley, and the Dakhla oasis at 500 km.

In the Kharga oasis the Nubian Sandstones are covered by rocks of Cretaceous and Tertiary age. Rocks occurring over Nubian Sandstones are destroyed by wind erosion. The altitude of the nearby plateau indicates that erosion has worn away and levelled about 200–300 m. of rocks.

The Nubian Sandstones are of continental origin. Their structure indicates that they are highly porous rocks, alternating with layers of clayey rocks, and irregularly distributed in horizontal and vertical directions.

Outcropping at the limits of southern Egypt and in the northern Sudan, the Nubian Sandstones absorb precipitation easily; in this area the quantity reaches more than 300 mm. a year.

According to data obtained by French investigators, the main supply region of Nubian Sandstones is situated in French Equatorial Africa, in the Ennedi region, where the quantity of atmospheric precipitation reaches 100 mm. yearly. Bore-holes in the Kharga oasis have depths of the order of 200 m., and in general reach only the upper zone of Nubian Sandstones. In 1931 the total number of wells was 670, in 1941 their number was 350. Towards 1953 their number was 412.

In 1941 the total yield of 350 wells was 123,200 $m.^3$ of water in 24 hours, and in 1953 the figure for 412 wells was about 10,580 $m.^3$.

During the past 30 years the yield of wells has decreased, and so has the general water-level in wells in comparison to the static level (by 2–4 m.).

Wells sunk at heights of about 100 m. above the level of the Mediterranean Sea are, as a rule, self-flowing. Wells that are sunk at greater heights have a water-level lower than the earth's surface.

It was noted that wells situated at a distance of about 700 m. from each other influence one another if they work simultaneously. The slope of the water-table in many wells reaches the value of 0.0505. The underground water current flows from south to north.

The chemical composition out of the water in the upper horizons of the Nubian Sandstones is as follows: dry residue, 220 mm./l.; chlorides, 50–70 mg.; total hardness, 10–15°; sulphates, 30–70 mg.; iron, up to 1 mg. Water temperature is in the 30–31° C. range.

As from 1939 bore-holes with a depth of 342–509 m. were sunk on the territory of the oasis. These bore-holes reached deeper water-bearing horizons of the Nubian Sandstones. It was noticed that the water-head increased with depth.

Total thickness of the water-bearing strata in deep wells does not exceed 10–15 per cent or, rarely, 25 per cent of the depth penetrated. In separate bore-holes the number of water-bearing beds reaches 25–30.

All the wells sunk at altitudes of about 100 m. or less are artesian. The chemical composition of the water is quite satisfactory for drinking and irrigation purposes. Dry residue does not exceed 200 mg. The chloride content is 70–100 mg., the iron content 0.5. The water has an odour of hydrogen sulphide.

All bore-holes with metallic casing are progressively destroyed by corrosion and last no more than 7–8 years. Thus, for instance, a well on the Borgh plot, sunk in 1940 and having a yield up to 400–500 m.^{3} in 24 hours, produced a yield that declined to 250 m.^{3} and, towards 1957, to 30 m.^{3}. Another well at Serukinoya that had a primary yield of 2,715 m.^{3} in 24 hours gave only 600 m.^{3} in 1952 and 200 m.^{3} in 1957. Investigations established that corrosion develops throughout the entire well and water flows through holes in the tubes into other water-bearing beds.

Since the construction of the first well, a decrease of up to 3 m. of the water head out of deep horizons has been observed.

In the Dakhla region, 200 km. to the west of the abovementioned oasis, there is also a great quantity of wells in the water-bearing horizons of Nubian Sandstones. Seven deep wells were sunk here, their construction being very similar to those in Kharga. These bore-holes were begun during the period 1940–51, and had depths of 221–353 m.

The distance between the wells is about 1 km., and that between groups of wells 10–15 km. Thickness of water-bearing horizons does not exceed 10 per cent of the geological cross-cut in all the wells.

In the south-western direction an increase of the water head and of the yield of wells can be observed. For instance, the Bhudkhulu well, during the initial exploitation period, yielded up to 9,000 m.^{3} in 24 hours (1941), and the Kasr No. 2 well to the north-east of it yielded about 6,500 m.^{3} in 24 hours.

The chemical composition of water in Dakhla is analogous to that of the water in Khargha. The water temperature reaches 34° C., with an air temperature of about 20° C.

There are many wells on the territory of the Dakhla oasis. They are sunk into the upper horizons of the Nubian Sandstones, their depth being around 200 m. The total number of wells in 1900 was 570, in 1931 it increased to 949. Only 60 per cent are self-flowing; from the remainder the water has to be pumped. Total yield of all the wells reaches 300,000 m.^{3} in 24 hours.

In the course of 50 years of operation the water level has decreased by 6 m. with a corresponding lowering of the yield of the wells.

The chemical composition of the water is satisfactory. The dry residue does not exceed 200–250 mg./l., the chlorides content is 30–50 mg., total hardness 66° and temporary hardness 26°.

The effect of wells is observable over distances of up to a kilometre.

Available data for the cases mentioned show that the rational utilization of Nubian water-bearing horizons and further development of new wells are closely dependent upon a thorough knowledge of underground-water resources.

To the north of the Dakhla oasis, the Nubian Sandstones occur at great depth and in the region directly bordering the Mediterranean Sea they were met at depths of several thousand metres.

According to data of Egyptian geologists, the water in Nubian sediments at great depths near the Mediterranean is mineralized.

Bearing in mind that the region of discharge of this water-bearing horizon is the Mediterranean Sea and that the washing out of Nubian sandy sediments is sufficiently intensive, we think that the question of the water type in the Nubian water-bearing horizon of the northern region of Egypt has not as yet received a satisfactory answer. Is it not possible that the high mineralization of water at such a depth occurs as a result of the mineralized waters of upper water-bearing horizons?

In Saudi Arabia the water-bearing horizon in Nubian Sandstone was reached by a bore-hole at a depth of over 1,100 m. At this depth the water level established itself higher than the earth's surface by 100 m. The yield of the bore-hole at the earth's surface was 50 l./sec. The mineralization of the water is up to 0.4 gm./l., and the temperature is higher than 40° C.

At the limits of the Turkmen Republic many underground water sources of varying mineralization are found in the area of Alpine folding; these sources are related to the Kopet-Dag thermal zone. On the borders of western Turkmenia is situated a great artesian basin. The underground waters are slightly mineralized and have the same temperature as natural sources: 35–37° C. Isolated sources (Archman) have an important yield. The waters of these sources are utilized not only for medical purposes, but also for irrigation.

In the region of Kopet-Dag waters of high head and varying mineralization are related to dipping water-bearing horizons in Tertiary and Cretaceous sediments. In the Uzbek S.S.R. waters in bedded and fissured sediments are largely developed at the limits of the artesian basin, near Tashkent and the Ferghana trough. In Tashkent (1,200 m.) a powerful fountain of slightly mineralized water was obtained from the Cretaceous water-bearing horizon; the temperature of the water was 40.1° C. The same horizon may yield underground water of great head above ground-level in the Golodnaya Steppe.

On the borders of the Ferghana trough water heads 800 m. above the surface were obtained in wells sunk into the Cretaceous strata; the yield in certain wells was several scores of litres per second. The presence of important heads in underground waters is also to be found in the arid zones of Pakistan and India; here again it is conditioned by the mountain systems, in which the supply of principal water-bearing horizons, included in trough-like folds, is to be found.

In a number of regions (Algeria, Tunisia, Libya and others), as a result of great heads in the lower horizons, the water is carried out from them into the strata of overlying rocks and into troughs with no discharge (shotts), where enormous water basins are formed. These regions of natural discharge (shotts) in the deep water-bearing horizons are important evaporation basins under arid climate conditions; on their periphery increased salt accumulation occurs from deep water-bearing horizons that are subject to pressure: the result is a gradual, large-scale salinization of vast territories. We think that the presence of shotts in the desert zones is one of the main factors to be taken into account when estimating the water balance of the territory under study.

An analysis of hydrogeological material and of data concerning the exploitation wells shows that at the present time utilization of underground waters in certain desert and semi-desert zones is undertaken without due consideration of their natural resources. Consequently many wells which initially had important yields and water heads have declined in capacity and level in the course of further operations, and have shown, in many cases, a marked increase of water mineralization.

The preparation of a map of artesian basins in the arid and semi-arid zones covered by the major Unesco project and of hydrogeological descriptions of these basins is a task of primary importance for the discovery and correct evaluation of the underground water reserves that could be used without disturbing the balance and the salt composition of underground waters.

RÉSUMÉ

Conditions de la formation d'eau douce, sous pression, dans certaines zones désertiques d'Afrique du Nord, d'URSS et d'Asie du Sud-Est (G. V. Bogomolov)

Des recherches effectuées dans toute une série de pays de l'Afrique du Nord ont permis d'établir que les plissements montagneux et les zones désertiques ou semi-désertiques qui les bordent représentent d'énormes dépressions artésiennes en forme de cuvettes ou situées à flanc de montagne, dans lesquelles circulent de puissants courants d'eaux souterraines qui ont une concentration minérale différente et dont la charge est de plusieurs centaines de mètres au-dessus du sol. La pression de l'eau dans les couches aquifères est déterminée par la différence de charge, en valeur absolue, qui existe entre l'entrée et la sortie des eaux. Pour ce qui est des horizons supérieurs, la concentration minérale des eaux souterraines passe de 0,3–0,8 gramme dans les massifs à 2–20 grammes dans les zones désertiques. La concentration minérale générale des eaux souterraines tombe, en profondeur, à 0,3–0,6 gramme de sels par litre. Dans certaines régions, et en fonction du cycle hydrologique, la concentration minérale aux horizons inférieurs change le long de la couche et l'on observe, de la zone d'alimentation à la zone d'écoulement, une transformation des eaux douces en eaux salines.

Dans les zones désertiques du Maroc, de l'Algérie, de la Tunisie, de la Libye, de la République arabe unie, de l'Arabie saoudite, du Pakistan, de l'Iran, de l'Inde, de l'URSS, de l'Australie, des États-Unis d'Amérique et d'autres pays, de semblables nappes d'eau sous pression couvrent actuellement une superficie qui varie de plusieurs centaines à un million des kilomètres carrés. Des eaux artésiennes et souterraines sont enfermées dans des roches d'âge géologique différent. C'est dans les couches aquifères enfermées dans les sédiments du crétacé inférieur et du crétacé supérieur que l'eau est le plus abondante. Dans certaines régions, des puits de plus de 1 000 mètres de profondeur ont un débit de 100 litres par seconde, une charge allant jusqu'à 100 mètres au-dessus du sol et une température de 30 à 45° C. Ils donnent de l'eau potable, qui est utilisée pour la consommation courante et pour l'irrigation et contient surtout de l'hydrocarbonate de calcium.

Dans diverses régions (Algérie, Tunisie, Libye, etc.), en raison de la puissance de la charge dans les horizons inférieurs, les eaux atteignent la masse des roches superposées et des dépressions avec un coefficient d'écoulement nul et elles forment de vastes lacs (chotts). Ces régions de décharge naturelle des eaux souterraines contenues dans les horizons inférieurs constituent, du fait des conditions climatiques du désert, d'importants bassins d'évaporation. Les sels apportés par les eaux sous pression des horizons inférieurs s'accumulent sur la périphérie de ces bassins et entraînent la salinisation progressive de vastes territoires. A notre avis, le problème des chotts est, dans les zones désertiques, l'un des principaux éléments à prendre en considération lorsqu'on vérifie le bilan hydrique du territoire où s'effectuent les recherches.

Une analyse des données et documents d'hydrogéologie relatifs aux puits exploités montre que dans certaines régions désertiques et semi-désertiques, les eaux souterraines sont actuellement utilisées sans qu'il soit tenu compte de l'importance des ressources naturelles; il en résulte que de nombreux puits qui, au départ, avaient une pression et un débit élevés, voient leur capacité et leur niveau baisser en cours d'exploitation et qu'on assiste, dans certains cas, à un accroissement de la concentration minérale de l'eau.

L'établissement d'une carte, accompagnée des descriptions hydrogéologiques correspondantes, des nappes artésiennes des zones désertiques et semi-désertiques – couverts par le projet majeur de l'Unesco – est d'une importance primordiale pour l'inventaire et l'évaluation exacte des ressources en eaux souterraines qui pourraient être utilisées sans que cela entraîne de perturbations dans le bilan des eaux souterraines ou dans la composition saline de l'eau.

DISCUSSION

N. Ahmad. Professor Bogomolov has dealt with subsoil flow in several countries and has also mentioned Pakistan. I want to add for his information that the greater part of West Pakistan is made up of alluvial plains the thickness of which at places is more than 5,000 ft. In a depth of 300–600 ft. no artesian pressure has ever been noticed. This type of flow with artesian pressure is observable in the Quetta region, where *Kerrize* (subsoil flow streams) are made use of to exploit the underground water.

Now I want to request Dr. Bogomolov to give an idea of subsoil flow where artesian pressure occurs, if the flow is limited to special streams or if it takes place as a sheet flow throughout the fissures of the formations.

G. V. Bogomolov. In alluvial deposits water flows in porous substrata, like a stream with a free surface. When flowing in a porous bed with water-tight beds above and below, the water may have some local head. When an alluvial valley overlies an artesian slope, then some pressure may be involved, and when drilling wells some head ought to be obtained. Such conditions are well-known from the published works on Algeria, Tunisia, Morocco and some areas in the USSR.

I. Zafar. (1) It is stated by Mr. Bogomolov that these wells suffer from interference when pumped simultaneously at a distance of less than 700 m. May I ask the author to elucidate please whether this distance determining the interference phenomenon holds good for only a few wells, or for the area as a whole irrespective of location of recharge sources—lakes, rivers, etc.—and the composition of soil strata?

(2) The author states that the water flows through holes in the tubes into other water-bearing beds. Such a situation develops in the recharge wells when reverse flow of artificially-fed recharge water is produced. May I request Mr. Bogomolov to explain how the normal tube well water can have a reverse flow leak into the subsoil strata, especially when the groundwater feeding a well may be under artesian pressure?

G. V. Bogomolov. (1) The interference of wells takes place when the intake zones overlap. Near rivers and lakes the problem will inevitably take some other form because of the influence of the water currents coming therefrom. The geology of a given location must also be taken into consideration.

(2) Such a phenomenon will occur when holes have developed in the well casing as a result of corrosion. If the pressure in the higher strata traversed by the well is lower than that of the lower strata, outward flow from the tube well will occur.

H. Schoeller. Est-ce que l'auteur a pu réunir de la documentation sur la vitesse de circulation de l'eau et également sur l'alimentation des diverses nappes sous pression des régions désertiques étudiées?

G. V. Bogomolov. There are different velocities for various soils: for sand soils—from some metres to tens of metres; but for fissured rocks with intensive cracking—from some tens of metres upwards. Here also, the head of water plays an important role.

CONDITIONS OF FORMATION OF SALINE WATERS IN ARID ZONES

by
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One of the principal problems in the development of deserts is the problem of a rational utilization of water resources in these areas. Resources of non-saline water in arid zones consist of superficial and underground currents, and of water obtained artificially by the desalinization of salt water.

Superficial currents are represented by rivers, which in some cases provide a sure solution for problems of water-supply and the irrigation of vast territories; this is the case in the United Arab Republic on account of the Nile, or in Pakistan on account of the Indus. Nevertheless, in the great majority of cases, rivers in arid zones rapidly lose their waters in the deserts. Besides rivers, however, there exist in deserts dry river-beds *(oueds)* that fill up with water from superficial outflow during periods of flooding, but later lose their waters rapidly; isolated lakes; estuaries; and tanks,[1] out of which water is sometimes used for the supply of towns (e.g. Calcutta).

Underground waters of arid zones may occur in the upper belt of the earth's crust, where they are submitted to the influence of the climate (ground-waters and shallow artesian waters) and, below this layer, in the lower belt of the earth's crust where the influence of the climate is practically excluded (deep artesian waters). According to their chemical composition underground waters of the upper belt may be non-saline or saline.

In the upper belt underground waters occur in outwash sediments of sub-mountain regions, where the usual tapping forms are underground galleries. In the Central Asian Republics of the Soviet Union they are called *kiariz*, in Morocco *rettara*, in Tunisia and Algeria *foggara*, in Pakistan and India *karez*. In some towns of North Africa and Pakistan underground galleries are the unique source of water-supply for cities; for instance Marrakesh in Morroco, Quetta in Pakistan. Water tapped by underground galleries is usually non-saline or only slightly mineralized in:—alluvial sediments of transit rivers and near irrigation canals, where lenses of fresh water are formed, attaining breadths of up to 1,000 m.; —dunes where lenses of fresh waters also arise; these lenses, it seems, are floating on saline waters.

A characteristic example is that of ground-waters in the dunes on the Mediteranean coast of the United Arab Republic; at the foot of mountain slopes, enclosing deserts, or in small artesian basins. A large number of such basins are to be observed in the folded formations situated on the arid zone territory of the Soviet Union, North Africa and Hindustan. Depending on the lithology of water-bearing rocks and on the gradient of artesian structures, underground waters therein may be non-saline or saline: fresh waters are usually contained in limestones, pebble-beds, coarse-grained sandstones and sands, and salt waters in clayey rocks.

Recent (young) tectonic disturbances of the trough type, filled up with thick masses of friable formations, have a special place in the hydrogeology of North Africa. In some cases they contain important reserves of non-saline underground waters and are the principal sources of water-supply for big cities.

On the rest of the territory, including vast desert areas, salted ground-waters are as a rule developed.

The distribution of non-saline and saline ground-waters in deserts of the arid zone is subordinated to the hydrochemical zonality, which consists in the following: on passing from more humidified zones to less humidified zones a gradual salinization of waters occurs, and they undergo a successive transition from hydrocarbonate waters, through sulphate ones to sulphate-chloride and chloride-sulphate waters, attaining a concentration of more than 100 gm./l. This process of alteration of the chemical composition of the ground-waters may be expressed by

$$HCO_3' \longrightarrow SO_4'' \longrightarrow SO_4'' \cdot Cl' \longrightarrow Cl' \cdot SO_4''.$$

Salinization is connected with the process of leaching salts out of the rock during the time of ground-water filtration from the supply region to the places of

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[1] Tanks are artificial reservoirs.

discharge; and also with the simultaneous processes of base exchange, salt concentration and, subsequently, salt precipitation after a solubility limit has been attained, first by carbonates of iron, calcium and magnesium, and later by calcium sulphate; this leads finally to a change in the chemical composition of ground-water.

The alkalinization of the rock may be divided into a filtration and a diffusion process. Filtration alkalinization consists in the dissolution of salts in the rock pores and in their being carried out by the filtration flow. Diffusion alkalinization is a diffused transfer of salts in clayey, irregularly salted rocks; it takes place in the presence of a concentration gradient.

In order to study the process of the alkalinization of saline rocks by non-saline waters, we carried out experimental investigations on the process of successive alkalinization of saline clayey loams, taken from various depths out of a hole in the Caspian lowland (USSR), the northern part of which belongs to the semi-arid zone, and the southern part to the arid zone. The investigations consisted in the following. A cylinder was turned out of the first sample and put into a glass tube with a drawn-off lower rim for pouring out the filtrate. The narrow space between the cylinder and the wall of the glass tube was filled with paraffin. After this, non-saline water was poured into the tube for filtration through the sample of clayey loam, while the level during filtration was constant. Water, having filtered through the first sample of clayey loam, was then successively filtered through the other samples of clayey loam taken from a greater depth and put into glass tubes in the same way as in the first tube. As a result of successive filtrations solutions were obtained, the chemical analyses of which permitted to establish how changes in the chemical composition of the water occur in a successive alkalinization of clayey loams. The results of this experiment are shown in Table 1.

From these data one may see that solutions nos. 1 and 2 had a sulphate type of mineralization, i.e. the quantity of dissolved sulphates in them exceeded substantially the quantity of dissolved chlorides and hydrocarbonates. Solution no. 3 had a sulphate-chloride type of mineralization: in it, along with sulphates, chlorides were present, but the quantity of sulphates was greater in comparison to the chlorides content. Solutions nos. 4 and 5 had a chloride-sulphate type of mineralization: the quantity of dissolved chlorides here exceeded the quantity of sulphates. In this way, after a successive alkalinization of saline clayey loams, first a sulphate was obtained out of the non-saline hydrocarbonate water, later a sulphate-chloride water and, lastly, a chloride-sulphate water, i.e. the water underwent the same changes of chemical composition by which the hydrochemical zonality of ground-waters was determined.

Let us examine the processes by which the chemical composition of the water changed during the experiment.

At first, during the filtration of the water through the clayey loams, a leaching of salts soluble in water took place. As a result of this hydrous solutions were formed (nos. 1, 2, 3), containing $Ca(HCO_3)_2$, $CaSO_4$, $MgSO_4$, NaCl. Depending on the NaCl concentration the solutions obtained had a different type of mineralization: sulphate type, with a concentration of $NaCl < 10$ meq./l.; sulphate-chloride type, with a concentration of $NaCl > 10$ meq./l.

A specific peculiarity of the solutions is the presence of Na_2SO_4; therefore they may be grouped under a general heading of sulphate-sodium solutions. The Na_2SO_4 concentration may attain in these solutions 1.9 gm./l. The formation of Na_2SO_4 in solutions took place during the leaching as a result of an exchange-adsorption process and of a subsequent replacement reaction:

$$\underset{\text{(rock)}}{2\,Na} + \underset{\text{(solution)}}{Ca(HCO_3)_2} \rightleftarrows \underset{\text{(rock)}}{Ca} + \underset{\text{(solution)}}{2\,NaHCO_3}$$

$$2\,NaCO_3 + CaSO_4 = NaSO_4 + Ca(HCO_3)_2$$

Subsequent filtration of sulphate-sodium solutions through clayey loams of deeper horizons further developed leaching processes of exchange adsorption and replacement. As a result, the concentration of solutions augmented and they passed from sulphate-sodium to chloride-sulphate ones; first to chlorine-magnesium ones (solution no. 4), characterized by the presence of $MgCl_2$, and later to chlorine-calcium (solution no. 5), chararacterized by the presence of $CaCl_2$. From the data in Table 1 it may be observed that Na_2SO_4 is absent from chlorine-magnesium solutions and Na_2SO_4 and $MgSO_4$ are absent from the chlorine-calcium solutions.

The formation of $MgCl_2$ and $CaCl_2$ is connected with exchange-absorption processes:

$$\frac{Mg''}{\text{(rock)}} + \frac{2\,NaCl}{\text{(solution)}} \rightleftarrows \frac{2\,Na'}{\text{(rock)}} + \frac{MgCl_2}{\text{(solution)}}$$

$$\frac{Ca''}{\text{(rock)}} + \frac{2\,NaCl}{\text{(solution)}} \rightleftarrows \frac{2\,Na'}{\text{(rock)}} + \frac{CaCl_2}{\text{(solution)}}$$

After the appearance of $CaCl_2$ in solutions the replacement reactions Na_2SO_4 for NaCl and $MgSO_4$ for $MgCl_2$ begin:

$$NaSO_4 + CaCl_2 = 2\,NaCl + CaSO_4$$

$$MgSO_4 + CaCl_2 = MgCl_2 + CaSO_4$$

In this way, $CaCl_2$ on the one hand, and $NaSO_4$ and $MgSO_4$ on the other, exclude one another; they are salt-antagonists. From an examination of the aforementioned reactions, it may be seen that exchange-adsorption processes, during the leaching of saline rocks, are carried out in two directions: (a) in unsalted or slightly mineralized solutions there occurs a dissolution of Na′ and, more rarely, of Mg″ out of the saline rock—as a result the formation of hydrocarbonates and of sodium and magnesium sulphates takes place; (b) with salted waters residues of Ca″ and, more rarely, Mg″ are dissolved—as a result calcium and magnesium-chlorides are formed.

Non-saline artesian waters are to be found on the borders of artesian basins, and saline waters on the outer limits of their central parts. This general statement is not quite true in cases in which the movement of underground water at depth is more intensive than in the upper horizons. Usually this takes place in water-pressure

Table 1. Ion and salt composition of solutions in experiment of successive leaching of saline clayey loams

Solution	Ion composition				Salt composition				Formula of chemical composition
	Ions	gm./l.	meq.	%	Salts	gm./l.	meq.	%	
No. 1	HCO_3'	0.124	2.03	4.78	$Ca(HCO_3)_2$	0.165	2.03	9.55	
	SO_4''	0.875	18.21	42.87	$CaSO_4$	0.257	3.77	17.74	
	Cl'	0.035	1.00	2.35	$MgSO_4$	0.272	4.52	21.29	
	Ca''	0.116	5.80	13.65					$M_{1.5}\,\frac{SO^4{}_{43}}{Na_{26}Ca_{14}}$
	Mg''	0.049	4.52	10.64	Na_2SO_4	0.705	9.92	46.71	
	Na'	0.251	10.92	25.71	NaCl	0.058	1.00	4.71	
	Total	1.45	42.48	100.00	Total	1.45	21.24	100.00	
No. 2	HCO_3	0.21	3.44	3.56	$Ca(HCO_3)_2$	0.278	3.44	7.12	
	SO_4	1.74	36.23	37.53	$CaSO_4$	0.528	7.76	16.07	
	Cl	0.305	8.60	8.91	$MgSO_4$	0.396	6.68	13.63	
	Ca	0.224	11.20	11.60	Na_2SO_4	1.555	21.89	45.35	$M_3\,\frac{SO^4{}_{38}}{Na_{32}Ca_{12}}$
	Mg	0.08	6.58	6.82					
	Na	0.70	30.49	31.58	NaCl	0.503	8.60	17.83	
	Total	3.26	96.54	100.00	Total	3.26	48.27	100.00	
No. 3	HCO_3	0.112	1.84	0.97	$Ca(HCO_3)_2$	0.150	1.84	1.95	
	SO_4	2.94	61.21	32.37	$CaSO_4$	1.617	23.76	25.13	
	Cl	1.117	31.50	16.66	$MgSO_4$	0.688	11.43	12.09	
	Ca	0.513	25.60	13.54	Na_2SO_4	1.848	26.02	27.52	$M_6\,\frac{SO^4{}_{32}Cl_{17}}{Na_{30}Ca_{13}}$
	Mg	0.139	11.43	6.04					
	Na	1.323	57.515	30.42	NaCl	1.841	31.50	33.31	
	Total	6.14	189.09	100.00	Total	6.14	94.55	100.00	
No. 4	HCO_3	0.087	1.43	0.50	$Ca(HCO_3)_2$	0.116	1.43	0.99	
	SO_4	2.75	57.26	19.86	$CaSO_4$	2.891	42.48	29.46	
	Cl	3.03	85.45	29.64	$MgSO_4$	0.889	14.78	10.26	
	Ca	0.88	43.91	15.23	$MgCl_2$	0.236	4.96	3.44	$M_{8.8}\,\frac{Cl_{30}SO^4{}_{20}}{Na_{28}Ca_{15}}$
	Mg	0.240	19.74	6.85					
	Na	1.85	80.49	27.92	NaCl	4.705	80.49	55.85	
	Total	8.84	288.28	100.00	Total	8.84	144.14	100.00	
No. 5	HCO_3	0.061	1.00	0.26	$Ca(HCO_3)_2$	0.08	1.0	0.51	
	SO_4	2.43	50.59	13.06	$CaSO_4$	3.44	50.59	26.12	
	Cl	5.04	142.13	36.68					
	Ca	1.54	76.845	19.83	$CaCl_2$	1.40	25.26	13.04	$M_{11\,4}\,\frac{Cl_{37}SO^4{}_{13}}{Na_{23}Ca_{20}}$
	Mg	0.36	29.605	7.64	$MgCl_2$	1.41	29.61	15.28	
	Na	2.01	87.27	22.53	NaCl	5.10	87.26	45.05	
	Total	11.44	389.44	100.00	Total	11.44	193.72	100.00	

structures, the lower parts of which are filled up with washed sediments. In the indicated conditions there are at depth non-saline or weakly mineralized waters, covered in the upper parts of the structures by saline waters. As examples we can take the deep horizons of the desert of Kyzyl-Kumy (USSR), where at a depth of about 2,000 m. in the Lower Cretaceous sediments unsalted, alkaline waters occur. In the upper parts of the structure they are covered by salt waters. Similar conditions exist in the Sahara, in Saudi Arabia and in the United Arab Republic.

Saline artesian waters occurring at great depths are divided into two groups:

1. *Chlorine-calcium waters.* This is the abbreviated name for chloride-sodium-calcium waters (Cl'-Na-Ca''). The total salt concentration of such waters is 50–250 gm./l. The composition of the waters includes sodium chloride and calcium and magnesium chlorides; this is the specific feature of their chemical composition. Carbonates and sulphates are absent in the waters or are present in small quantities.
2. Alkaline waters. This is the abbreviated name for chloride-hydrocarbonate-sodium waters (Cl'-HCO_3'-Na'). An essential part of the salt composition of these waters is formed by sodium chlorides and carbonates; sulphates have a subordinate importance. Salt concentration is lower than in the preceding group and does not exceed 20–50 gm./l.

The formation of the chemical composition of deep saline waters is a complex process. There exist two points of view regarding the formation of saline artesian waters:

(a) deep saline waters are sedimentation waters, conserved in the deposits of the last sedimentation epochs, that were later gradually driven back into marine basins by non-saline waters arising from infiltration occurring in the border parts of structures; (b) deep saline waters are waters that are forming as a result of the metamorphosis of infiltration waters. The principal processes are: concentration of waters under the influence of the removal of molecular H_2O; the exchange-adsorption processes; sulphate reduction under the influence of the activity of sulphate-reducing bacteria. As a result of concentration the quantity of dissolved salts increases up to 100–250 gm./l.; during exchange processes calcium and magnesium chlorides are formed (in chlorine-calcium waters) or sodium hydrocarbonates (in alkaline waters); during sulphate reduction processes the biochemical recovery of sulphates, with formation of hydrogen sulphide, takes place.

In studying the formation of the chemical composition of deep artesian waters in arid zones, it is necessary to take into account the fact that deep waters are in a state of very slow movement. So, for instance, in Algeria, the movement of deep waters in Lower Cretaceous sediments has been established by piezometric readings; in the Kyzyl-Kumy desert the movement of deep underground waters in Lower Cretaceous sediments is also evident; on the eastern shore of the Caspian Sea an underground outflow of deep waters into the sea has been established, etc. Generalizing from the material available about deep underground waters, one may come to the conclusion that the movement of deep underground waters covers great areas of platforms and of adjoining submountain sags, on which arid zones are often found. For instance, in the Soviet Union the Kara-Kumy desert borders on the Prekopetdag submountain sag, and the Kyzyl-Kumy, the Mouun-Kumy and the Bek Pat-Dala deserts border the sags of the Thian-Shan mountain range; in Morocco arid zones begin in the region of the pre-African submountain sag and at the northern end of the South African shield; in Pakistan and India the Radjastan deserts enter as a composite part into the western section of the Hindus-Ganges sag. In all the structures mentioned there exists at depth a movement of underground waters and their outflow towards the region of discharge. The movement of deep waters has a complicated character dependent on the heterogenous rock structure along the watercourse, the presence of lithological and structural barriers, and fault displacements.

The direction of the main outflow movement of deep waters depends on the relative positions of the feeding and discharge regions; the speed of movement depends on the gradient and on the physical properties of the water (specific weight, viscosity, temperature), and on the porosity and thickness of the water-conducting beds. Besides the movement of deep waters in one direction, movements in various different directions may occur. For instance, in the Turonian water-bearing horizon of southern Tunisia, in the region of the Djerid shott, a movement of deep waters in three directions was established: southern, almost latitudinal, and north-eastern; this is connected with the presence of structural barriers on the route followed by deep water. Very interesting is the deep water movement in the form of two opposite currents. It occurs when there are two feeding regions, situated at two diametrically opposite ends of the discharge region. For instance, in Algeria there are two feeding regions of deep waters: to the north of the Atlas *mountain* range, and to the south of the Akhaggar plateau. A broad band of shotts, extending almost in a latitudinal direction through the central part of Algeria, serves as a discharge region. The movement of underground waters occurs in two directions—from north to south (main direction) and from south to north. In the *shott* zone the opposite deep water currents unite and discharge under a high head directly through the saline clayey surface of the shotts, forming on the surface small depressions of the crater type, or on the banks of the shotts in the form of ascending thermal sources. Along with the deep water movement, taking place under the influence of the hydrodynamic head, the movement of water particles under the influence of the forces of resilient compression, osmosis, diffusion and self-diffusion acquires great importance at depth.

Palaeohydrogeological analysis and, as part of it, the examination of the oscillatory movements of the earth's crust in the limits of the region studied, has great importance for the study of the conditions for the composition of the deep salt waters. According to contemporary views, the oscillating movements of the earth's crust may be represented in the form of two interconnected groups: orogenic movements and epeirogenic movements. By the first, one understands ascending movements of great amplitude, starting in geosyncline regions and expanding from there onto the platform; by the second, ascending and descending movements of small amplitude, occurring simultaneously in geosyncline regions and on platforms in one or in various directions. As a result of orogenetic movements, the formation of mountain structures on the earth's surface takes place, with the formation of troughs and arches.

Orogenic movements lead to a sharp change in the relief of the earth's crust, and are usually accompanied by mechanical deformation of rocks. As a result of the movements the whole system of hydrodynamic and geochemical equilibrium in underground waters created earlier is upset; there occurs a displacement of their feeding and outflow regions, a connexion between different water-saturated rock complexes along the systems of arisen or revived fissures, the outflow of deep saline waters, their mixing with underground waters of upper horizons, release of gas from the waters and their outflow into the drainage regions. In this connexion, periods of orogenesis are periods of intensive water-exchange; the water cycle in the earth's crust increases sharply during this time.

Epeirogenic movements also create new conditions of underground water movement. On the basis of a detailed analysis of the history of the development of various regions in the USSR, it was established that during the positive phases of epeirogenesis desalinization of water-bearing horizons takes place in the elevated parts of the dry land and, in the deeper parts, the heavy salt waters are squeezed out by the unsalted waters, and flow to the drainage regions. As a result of this squeezing a slow displacement of unsalted waters from their feeding regions to the outflow region occurs. Negative forms of epeirogenesis create, on the other hand, a slowing down of the movement of underground waters towards the outflow regions.

By studying the history of oscillatory movements of the earth's crust in a definite structural region, one can establish the periods of water accumulation, of water exchange with the surface, the continental and marine periods, and a series of other moments that facilitate the restoration of the geological history of underground waters. The application of palaeogeographic methods in the USSR has made possible the formulation of hydrogeological laws for the formation of deep salted waters on platforms and in regions of foldings. There is no doubt that the application of this method to the study of conditions related to the formation of underground waters in North Africa, the Arabian Peninsula, Asia and other regions will give us a more precise knowledge of the hydrogeological laws of the arid zones and of the distribution of salted and unsalted waters in them.

RÉSUMÉ

Conditions de la formation des nappes d'eau saline dans les régions arides (A. I. Siline-Bektchourine).

Le processus d'accumulation des sels dans les eaux souterraines de la zone aride comprend les phases suivantes: alcalinisation du complexe salin des roches, échanges de cations, concentration de l'eau sous l'effet de l'évaporation, et précipitation des sels quand le seuil de solubilité est atteint. La précipitation des sels comprend à son tour trois étapes: il s'agit d'abord de carbonates, puis de sulfates, enfin de chlorures.

Dans le cadre d'études expérimentales du processus d'alcalinisation on constate, en observant la filtration de l'eau à travers la roche, que la salinisation comporte également plusieurs étapes. Au cours de la première apparaissent des eaux alcalines, qui se transforment en eaux saumâtres chargées de sulfates et de natron. Puis la teneur en sels augmente, les eaux saumâtres deviennent des eaux salines, pour donner enfin une sorte de saumure minéralisée contenant des chlorures et des sulfates. Dans les conditions naturelles, les processus d'alcalinisation de ce genre s'accompagnent d'une réduction des sulfates: les sulfates disparaissent, et les eaux salines se transforment en saumure contenant des chlorures, du natron et du calcium.

Dans la partie méridionale des régions arides, il existe aussi et des eaux douces et des eaux salines. Leur répartition géographique dépend de celle des structures géologiques, ainsi que de la dynamique des écoulements souterrains. Les eaux douces se rencontrent en général dans les zones marginales des bassins artésiens et sur les bords des plateaux, où les eaux des strates profondes s'écoulent plus rapidement que dans les parties centrales des bassins artésiens; au centre de ces bassins, on trouve des eaux salines. Ces constatations sont mieux fondées encore dans le cas de structures géologiques délavées où le mouvement des eaux souterraines et leur écoulement vers les zones de décharge sont bien plus rapides.

La composition chimique des eaux profondes résulte d'actions complexes en cours depuis les époques géologiques. On distingue deux catégories d'eaux salines: les eaux sédimentaires, conservées dans les sédiments formés au cours des dernières époques de sédimentation, et celles qui proviennent de la métamorphisation des eaux infiltrées.

Quand on étudie les conditions dans lesquelles les eaux profondes se chargent de sels, il est indispensable de se rappeler que le mouvement de ces eaux n'est pas seulement dû à l'action de la gravité; il peut aussi s'accomplir par diffusion, par osmose, par séparation des liquides selon leur densité propre et selon le mouvement de translation des particules résultant de l'autodiffusion.

La porosité des roches variant de façon irrégulière avec la profondeur, et l'épaisseur des différentes strates étant également très variable, les mouvements des eaux profondes sont irréguliers. Les barrières structurales et lithologiques qui favorisent l'accumulation des substances dissoutes acquièrent donc une grande importance. Comme la vitesse de déplacement des eaux souterraines est en général assez faible, le transport des substances dissoutes ne s'effectue que dans des proportions peu considérables; il arrive aussi que les déplacements du solvant et ceux des substances dissoutes ne coïncident pas.

En vue de préciser nos connaissances relatives à la formation des eaux salines dans la partie méridionale de la zone aride, il est nécessaire d'effectuer une étude paléographique, hydrologique et géologique des grandes régions qui contiennent des complexes de structures hydrogéologiques. En URSS, cette méthode a permis d'élucider les lois hydrogéologiques de la formation des eaux profondes dans la plaine russe et dans les plissements alpins limitrophes, où l'on trouve beaucoup de terres arides.

THE INFLUENCE OF THE GEOLOGICAL CONDITIONS ON THE SALINITY OF THE ZAM RUD

by
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GEOLOGICAL SETTING

The present photo-geological map of the area between the Zam Rud and the Hable Rud is based on vertical air photos (WWS-Survey) and field information. It shows clearly the positions, limits and extent of the salt domes as well as the trend and development of the evaporite formations in relation to the plugs.

The salt diapirs

The salt diapirs are arranged in a south-west trending zone, connecting the big salt dome area between Aivaneki and Garmsar with the salt plugs around Kabutar Darreh.

Most of the plugs have an extensive and rather thick gypsum cap-rock which partly conceals the underlying rock salt.

Where breaking through bedded formations, a sharp upturning of the beds along the contact is often recognizable.

The salt domes between Aivaneki and Garmsar contain many lenses, blocks, dykes and larger masses of basic igneous rocks, mostly augite dolerites. They are usually related to the gypsum cap-rock and rarely found in the rock salt itself. This suggests an original position of the flows above the deposited evaporite.

The salt plugs further north-east contain no traces of igneous rocks.

Below the gypsum cap-rock, an argillaceous-marly impervious zone, showing strong folding and contortion, is usually exposed. This second cap-rock changes quickly into more or less pure rock salt. The sling-texture and contorsion might be related to the squeezing and screwing action of the frame on the plastic salt during the intrusion.

Along the southern rim of the salt plug north-east of Aivaneki, a large number of contorted sandy-marly red beds are found, and real rock salt sets in only below the gypsum cap-rock.

Some of the plugs are clearly related either to intersections of fault zones or to folds. Others do not appear to be related to structure.

The salt domes south-west of Kabutar Darreh are situated on a syncline in the Miocene Upper Red Formation.

The section in the Lower Zam Rud

The geological section along the Zam Rud discloses formations of Eocene to Quaternary age, and in order to understand the origin of the evaporites and the salt water, we shall explain this type section, starting at Aivaneki and ending above Varaneh.

The youngest, probably Plio-Pleistocene, beds are exposed in the gravel ridges north of the Meshhed road at Aivaneki. These loosely cemented gravels have a good permeability and are good aquifers. They contain no evaporite intercalations or gypsiferous cement and are in fact in many places drained by kanats between Aivaneki and Sharifabad. They lie on steeper south-dipping Bakhtiari-type conglomerates and sandstones, which are well exposed in the high bluff south of Pamelokh.

Between Pamelokh and DoAb, we have seen exposures of Mio-Pliocene strata dipping 20°–35° SSW., and comprising a total thickness of almost 5,000 m. This Upper Red Formation contains two members with evaporites. The upper member of Pamelokh is marly-gypsiferous, without rock salt beds in this section but with an increasing amount of gypsum towards the south-east. Between Ahmadabad and DoAb are thick sandstone beds with interbedded siltstones and mudstones, and including some conglomerate beds, forming the higher crests. The conglomerates considerably increase towards the north-west, whereas the mudstones increase in a south-easterly direction. This middle portion of the Upper Red Formation has a thickness of 2,500 m. It contains evaporite minerals only in the frequent gypsum veins in the mudstones. In spite of the sandstones and conglomerates, the formation is not a good aquifer because of the frequent interbedding of impervious marls, and the poor fracturing and low permeability of the calcareous and partly argillaceous sandstones and conglomerates. In fact, not a single sizeable spring is found in the map area in this formation.

Between DoAb and Varaneh, the lower part of the Upper Red Formation consists of 700 m. of red marls, siltstones, fine-grained, cross-bedded sandstones, green marl and gypsum beds. The gypsum horizons are very pliable beds and cause the incompetent folding in this member in the surroundings of Varaneh. Furthermore, the gypsum is partly accumulated in diapiric masses, combined with rock salt, and forms small plugs in this formation south and south-east of the village of Varaneh.

We call this member the Upper Evaporite, although along the Zam Rud it is only partly made up of evaporites. The formation is impervious and contains no springs. It can, however, contribute sulphate and chlorides to the rivers flowing across, and also by means of rain water falling on it and partly dissolving the evaporites. This is evidenced by the comparison of the water samples no. 6, taken at DoAb and containing 0.72 gm./l. of sulphate, and no. 7 taken above Varaneh and containing only 0.29 gm./l. sulphates (see Table 1). Stratigraphically below this evaporite zone, we find at Varaneh nearly 200 m. of Oligo-Miocene limestone, alternating with marls. This marine limestone formation is partly highly permeable by fracturing, and several springs issue from the upper contact against the impervious Upper Evaporite south of Garmsar. These are fresh water springs, but we have not yet made an analysis for comparison with the other spring or river waters.

To the north-west, at Bolan, the marine Oligo-Miocene limestone interdigitates with red-brown, hard-cemented conglomerates, which underlie as Lower Red Formation the limestone of Varaneh.

Below these Lower Red beds follows the most important Lower Evaporite Formation—a thickness of 570 m. of porous, saccaroidal gypsum exposed west of the valley, above Varaneh. The gypsum plunges into the core of a west-north-west to east-south-east trending anticline. The gypsum zone is partly porous and several springs with sulphatic water are found along the upper or lower contact. A small spring with H_2S gas is found in a lens of this Lower Evaporite near the oil seepage of Solk.

To the east, one can actually see the emergence of an important salt dome with gypsum cap-rock from this Lower Evaporite Formation, pushing through the Oligo-Miocene limestone on the plunge of the Varaneh anticline. The salt merges with evaporites from the Upper Evaporite Member, forming an apophyse along the south flank of the anticline.

The river Garmsar flows around this salt plug; it is first contaminated by sulphatic water from a spring out of the gypsum cap-rock, and further down by saline water from the salt plug (see above).

The same Lower Evaporite Formation might also be the main contributor of evaporites into the salt plugs, penetrating the Upper Red Formation between Kabutar Darreh and Aivaneki.

Further upstream, but stratigraphically below the Lower Evaporite, the Zam Rud cuts into the Eocene Green Beds. This highly fractured, partly siliceous and tuffaceous formation is a good aquifer and many small springs appear on the slopes of the mountains. Usually, the springs are connected with zones of fracturing or fault lines. They contain fresh water and our sample no. 7 might represent more or less an average composition. Two fresh-water springs were tasted along the fault line crossing the Zam Rud between Varaneh and Moghanak and one of the springs issuing from igneous rocks along the fault line west of Bolan was tasted on an earlier field trip.

The main supply of water into the Zam Rud, however, originates from the large and thick gravel deposits of probably Plio-Pleistocene age which form the peneplain that extends, south of the Firuzkuh road, from the Djadje Rud to the Hable Rud, and attains a thickness of several hundred metres at Simindasht. These clastic deposits may correspond in age to the gravel formation near Aivaneki, north of the Lower Meshhed road.

TABLE 1. Chemical analysis of water samples from Zam Rud area in gm./l.

Sample	Location	*p*H	CO_3'' HCO_3'	gm. SO_4''	per l. Cl'	Ca''	Mg''	Na'	Dissolved solids
No. 1	Cross-roads west of Garmsar	7.8	0.0178	4.15	46.0	1.98	0.36	28.5	83.8
No. 2	South end of Aivaneki fan	8.1	0.0417	2.21	1.78	0.54	0.13	1.34	6.3
No. 3	Spring from salt plug cap rock	8.25	0.0256	2.78	0.84	0.70	0.27	0.54	5.62
No. 4	Kanat north of Aivaneki	7.9	0.0434	1.00	0.70	0.29	0.07	0.44	2.36
No. 5	River water at Pamelokh	8.25	0.026	1.24	0.73	0.37	0.07	0.47	3.12
No. 6	River water at DoAb	7.9	0.045	0.72	0.25	0.24	0.05	0.16	1.62
No. 7	Kanat above Varaneh	8.0	0.050	0.29	0.15	0.12	0.03	0.04	0.75

WATER SALINITY IN RELATION TO GEOLOGICAL CONDITIONS

As regards the content of dissolved solids in the water samples, we may first look at the table of analysis and at the graphic representation of the results[1] (see Table 1, samples nos. 1, 2, 3, 4).

Starting with fresh water sample no. 7, taken from a kanat in the green beds, we find that it has the lowest content of sulphates and chlorides (only 0.29 gm./l. SO_4'' and 0.15 gm./l. Cl') and the highest content of carbonate and bicarbonate (0.05 gm./l. HCO_3'–CO_3''). Downstream, at DoAb (sample no. 6), after the river has flowed across the Lower and Upper Evaporites, the content of dissolved solids and of sulphates has more than doubled and the chloride content has already appreciably increased.

Further down, at Pamelokh, below the junction with the dry river bed from the large salt plug east of the lower Zam Rud, the sulphate content in sample no. 5 has increased to 1.24 gm./l. and the chloride content to 0.73 gm./l.

On the other hand, sample no. 4 shows again a lower dissolved solids, sulphates and chlorides content. The kanat from which this sample was taken draws its water mainly from the gravels of the Bolan valley. In this valley, west of the Zam Rud, the evaporites content in the Upper Red Formation is much lower than further east, and the Lower Evaporite does not extend westward into the Bolan valley.

Sample no. 2, from the lower end of the Aivaneki fan, has again a much higher dissolved solids, sulphates and chlorides content. The water tastes bitter and slightly saline. The salts may be supplied in part by the river east of the plain of Aivaneki, and may in part originate from the salt plug area south of the fan. A small spring emerging near the first outcrops of the salt diapir contains already highly saline and bitter water. On the other hand, a spring issuing from a gravel layer in the fan above the main aquifer contains fresh water, which is collected into an iron tube and used by the nomads, who graze their cattle on the arid plain east of Aivaneki during the spring.

Sample no. 3, from a spring in the cap-rock of a salt plug (it was from this one that I drank water in summer 1950), contains still more sulphates than no. 2, but less chlorides and dissolved solids.

The river bed draining this salt plug area contains concentrated salt water where it crosses the lower salt plug. On the other hand, the small flow of water in the same valley at the cross-roads is less saline. Fresh water from the Plio-Pleistocene gravel formation east of Aivaneki must have lowered the dissolved solids content between the salt plug and the road.

Sample no. 1 from the cross-roads situated on the edge of the plain of Garmsar is highly saline water. This high salinity might be partly produced by evaporation in the river bed between the points at which samples nos. 2 and 1 were taken. But as the flow of water at the place where sample 1 was taken is more than half the flow at the place of sample no. 2, the greater part of the salt content must be leached out from the salt formation through which the river is flowing. In fact, impure salt formation and blocks and fragments of rock-salt and gypsum are seen in many places along the river bed between the places at which samples nos. 2 and 1 were taken.

INFLUENCE OF SALT DIAPIRS ON SALINITY OF WATER

The comparison of the analyses of the samples nos. 2 and 1 shows how quickly under certain conditions river water can be contaminated by flowing across salt plug areas. A small flow in the river, combined with long stretches of rock salt exposures along the river bed and high evaporation, increases the salt content twelvefold over a distance of 10 km.

On the other hand, the example of the Hable Rud illustrates a different situation: in spite of flowing across a salt dome below Kabutar Darreh, the strong flow of water in this river is less contaminated by the salt plug than by the influx of concentrated salt water from salt tributaries further downstream. The swift current, the large quantity of water and the gravel cover in the river bed partly prevent contamination when the river is flowing across the salt plug.

The example of the tributary of the Zam Rud east of Aivaneki illustrates a third case: in spite of extensive drainage, this river is not perennial owing to lack of good aquifers in the upper part. It contains concentrated salt water in the salt plug area. The underground flow from the Plio-Pleistocene aquifer north of the Meshhed road is on the other hand strong enough to change the salt water of the upper part of the river into much less saline water in the lower part. If it were possible to eliminate the salt water from the salt plug area by damming and evaporation and to heighten the fresh-water flow by additional drainage through kanats, the water might even be suitable for irrigation.

INFLUENCE OF WATER SALINITY ON VEGETATION

In the Zam Rud system, the increasing amount of salt downstream as well as the changing structure of the soil are reflected in the vegetation and crops along the river. Fruit trees (apricots, apples, walnuts) are confined to the upper part and the gravely soil, down the Ahmedabad. At Pamelokh, in the more sandy-argillaceous soil, wheat, cucumbers and melons are cultivated. At Aivaneki, wheat, pomegranates, figs and some pistachios are grown. On the lower part of the Aivaneki fan, the soil is a silty argillaceous loam with a high water capacity. The water

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[1] U.S. Salinity Laboratory Staff, *Diagnosis and Improvement of Saline and Alkali Soils*, U.S. Department of Agriculture Handbook no. 60, 1954, 160 p.

table is high and irrigation in early summer is sufficient to start the growth of melons, which later in summer draw their slightly saline water from the absorbed flood water. These melons of excellent quality are the main crop of the area.

Further downstream, where the water table is cut by the stream course, the natural vegetation in the already bitter and saline water (represented by sample no. 2) is composed of gauze-trees and a peculiar sturdy reed, both indicative of saline and bitter waters.

RÉSUMÉ

Influence des conditions géologiques sur la salinité du Zam Roud (H. Huber)

L'auteur décrit les formations géologiques qui bordent le Zam Roud et la situation des diapirs de sel. Il indique les résultats de l'analyse chimique des échantillons d'eau prélevés en divers points de cette rivière, et il étudie les différents taux d'accroissement de la salinité des cours d'eau qui traversent des régions où existent des culots de sel. Il décrit également la végétation de chaque secteur des bords du Zam Roud et montre comment cette végétation est influencée par la salinité du cours d'eau, ainsi que par la structure du sol.

DISCUSSION

A. Hafiz. (1) I should like to know whether the speed of water and the quantity of water at a particular place have any effect on the degree of salinity of the water.

(2) When taking samples from one river at different places, have you taken into account the rate of flow of water at these different places?

H. Huber. (1) We have observed that the strong flow and swift current of the Habb Rud are not strongly influenced, and that the water is not seriously contaminated, when flowing across the salt plug (4–5 km.) south of Kabuhar Darreh. Salt contamination in the river results *primarily* from the influx of brine from salt water springs further downstream.

(2) In the Zam Rud the flow is partly superficial and partly underground, within gravels. We have taken samples both from the points of emergence of underground water (kanats), and from the surface flow. These latter samples (nos. 5, 6) may be more saline partly as a result of evaporation. On the other hand, both samples no. 5 (from surface) and no. 4 (from a kanat) have much higher salinity than no. 6 (from the surface further upstream), which shows that the salinity progressively increases downstream both in subsurface and in surface waters.

AN EXAMINATION OF GEOCHEMICAL DATA OF SUBSURFACE WATERS IN THE QUM AREA

by
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In the Qum area the geological factors seem to determine, at least in part, the nature of the underground waters. Some of these factors, however, are more universal in character. For example, we know that the sulphate content of subsurface waters associated with oilfields is generally lower than that of the average sea water [1, 5].[1] Some of the waters extracted from the Alborz deep wells show comparatively low sulphate content.

SAMPLING

The results of chemical analyses of the subsurface waters are more or less dependent on the method of sampling. It is obvious that any method of sampling fluid in a test well should be so designed as to make it possible to obtain a given volume of the formation fluid without its becoming contaminated with adventitious fluids. Serious attempts have been made to overcome the difficulties inherent in procuring uncontaminated representative samples by using specially designed samplers. One such sampler, briefly described by Delacour [4], consists of a specially made suction core barrel which adheres to the boring wall at the level of the formation to be studied. The fluid from the interstices is then sucked inside the suction core barrel which has a capacity of 25 cm^3. One important drawback of this method is that the quantity of fluid it provides is inadequate for analytical purposes.

The electrical formation tester [12] is another type of sampler designed and put into use for this purpose. The tester is operated against the wall of the hole at any depth desired. Zones to be tested are usually determined by a study of the electrical and micro-caliper surveys; and the data relating to the fluids in the formation are continuously recorded at the surface. Furthermore, the tester is capable of recovering up to 5.5 gallons of fluid. One disadvantage of this tester is that it fails to provide fluid, and even sometimes to operate, against hard and fissured formations. The simplest, and in certain cases the surest, method of sampling deep wells—especially in exploratory states—is by lowering the sampler into the well (if the pressure of the fluid-bearing formation is not high) or by allowing the well to flow either through a conventional tester [17], or simply through the open hole. In the Qum area the latter method was used. The water from the Feyz Abad well (an artesian one) was sampled at the well-head, as was that of Saradjeh water well no. 1 and of the Alborz no. 6 well.

The water from the Alborz no. 7 well was, however, made to flow through a Johnston tester. The water from other wells was pumped to the surface and was sampled at the well-head. It should be recalled that the deep waters (those coming from depths exceeding 3,000 m.) are usually very hot. Some of the waters obtained from wells nos. A.6 and A.7 showed a temperature exceeding 40° F. Furthermore, the results of frequent temperature surveys carried out in these wells indicate that some of the waters sampled at the surface may have—at depths exceeding 3,000 m.—temperatures greater than 200° F. Thus the rate of evaporation of these waters, when they reach the ground level, is much higher than that of shallower wells such as the Saradjeh water well situated north of the Saradjeh structure. Analysis of the deeper water will consequently give a slightly greater mineral concentration; in this work we have assumed the difference to be negligible.

INTERPRETATION

The efforts which resulted in the choice of the Qum area for exploratory drilling are described elsewhere [13]. This area is situated west of a salt-mud desert (Kavir) which lies to the west of the Great Salt Desert [9]. The formations outcropping or lying buried in this area are conveniently described as:

1. Lower Red Formations well developed in the Shurab region, which lies to the west of the Saradjeh district. It consists of red siltstones and marlstones with frequent gypsum layers and salt lenses.

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[1] The figures in brackets refer to the bibliography on page 56.

2. Oligo-Miocene Marine Formations consisting of a series of marls and limestone.
3. Upper Red Formation. The Oligo-Miocene Marine Formations occur below the evaporite formation which may be considered as the base of the Upper Red Formation. Gypsum is frequently found in the outcrop of the evaporites, but salt layers are rarer and may occasionally be concentrated in lenses. A thick development of uniform red-brown silty marlstones with thin sandy intercalations follows the evaporites; for practical field purposes this is called an Upper Red Formation. It should be pointed out here that the western plunge of the Alborz structure is pierced by the Kuh-i-Namak salt dome, consisting of rather impure and somewhat ferruginous salt [9].

The Alborz no. 6 and no. 7 wells penetrated through the very troublesome evaporites, which called for extremely delicate drilling-fluid control and special drilling techniques [7]. The other wells, however, namely the Faradj, Saradjeh, Keyvaniehs and Qara Chai wells, were drilled for water and the Separ-i-Rostam no. 1 well (SR. 1) was a comparatively shallow exploratory well drilled south of Separ-i-Rostam in order to test the underlying formation. There, after drilling through sands and gravels, water was encountered at about 10 m. from the ground level. Later a series of casings more than 90 m. long was inserted, in order to shut this off and carry on drilling through a part of the Oligo-Miocene Formation which crops out a short distance northward at the Separ-i-Rostam inselberg.[1]

The area is crossed by two rivers: the Qara Chai and its tributaries flowing eastward and some distance north of the Kuh-i-Namak salt plug; the Qum Rud, which it joins west of the Separ-i-Rostam and which comes from the south-west and flows through the town of Qum. Thus it may be seen that the Kuh-i-Namak salt plug is situated in the southern catchment area of the Qara-Chai, and some of the rain water flowing off the northern flank of the plug is naturally drained by the Qara Chai. This obviously accounts for the higher salinity of the water from the Qara Chai well, which is more than four times that of the Feyz Abad well. Note the still higher value of the salinity of the Keyvanieh well, which is not only situated in the southern catchment area of the Qara Chai but is also in very close proximity to the outcrop of the Upper Red Formation; this latter is much less affected by the subsurface hydrodynamic gradient than is the coarse-grained, loosely consolidated alluvium through which the Qara Chai well was drilled.

Similar reasoning applies to the salinities reported for the Alborz no. 6 and no. 7 wells, which correspond to the waters occurring at depths not exceeding 200–300 m. They are thus comparable to the salinities of the waters from previously mentioned water wells, with this exception that, whilst the salinities of the water from the latter wells have been determined by standard analytical methods, those of the shallow waters encountered in the Alborz no. 6 and no. 7 wells have been computed from a consideration of the electrochemical components of the S.P. curve. Similarly the salinity of the Faradj well water has been computed from the S.P. curve [10].

The chemical composition of waters obtained from depths of around 3,000 m. or more is quite different from that of the shallower waters discussed above. Waters of the former type were obtained from the Alborz no. 6 and no. 7 wells. Their well-head temperatures were high, and they were often accompanied by gas. They usually occur under very high pressures; for instance, tests on the Alborz no. 6 well showed that the shut-in pressure, after the well had flowed saturated saline water for some time, amounted to over 3,500 PSIG. Waters of this sort are also associated with the salt-bearing evaporite series, and are therefore highly saline (to the saturation point). Moreover they contain comparatively large quantities of calcium ions. This fact has been frequently observed in oilfield waters [5], and is a very useful guide which, in conjunction with other geochemical data, may serve to distinguish deep waters from the shallow ones when remedial measures are to be devised for shutting off various aquifers in deep wells and preventing them from contaminating lower, oil-bearing, horizons.

It may be noted that whilst the calcium/magnesium ratio (Rcm.) varies comparatively little, the chloride/sulphate ratio (Rcs.) varies widely, being 0.8 for the water from Feyz Abad well in the northern catchment area of the Qara Chai, and attaining the high value of 16 for the water from the Keyvanieh well situated in the southern catchment area of the Qara Chai (by Qara Chai we mean the Qara Chai river proper which flows through Asghar Abad, and a small seasonal stream flowing through Rustak and joining the Qara Chai east of Asghar Abad).

The salinity of the water from the Saradjeh water well reflects, to some extent, the nature of the salt-mud plain on the margin of which it is located. In addition, other factors, such as the probable absence of any subsurface hydrodynamic gradient, may also contribute to the increased salinity of the water from this well.

TABLE 1. Analysis of water from Separ-i-Rostam well no. 1

Specific gravity	1.02
*p*H	7.4
Calcium	190 ppm.
Magnesium	103 ppm.
Sodium	1 037 ppm.
Sulphate	650 ppm.
Chloride	1 598 ppm.
Salinity	2 580 ppm.

In addition, this water contained a small amount of CO_2 (about 150 ppm.).

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[1] See "The Oligo-Miocene Marine Formation in the Qum Region (Central Iran)", by Furrer and Soder, Section 1/A/5, *Proceedings, Fourth World Petroleum Congress.*

Table 2. Analysis of water from Feyz Abad well (probable depth, 100–200 m.)

*p*H	7.5
Calcium	60 ppm.
Magnesium	36 ppm.
Sodium	114 ppm.
Sulphate	345 ppm.
Chloride	283 ppm.
Salinity	290 ppm.

Table 3. Analysis of water from the Qara Chai River well (depth, 200–220 m.)

Density	0.9976 (26° C.)
*p*H	7.5
Calcium	113 ppm.
Magnesium	49 ppm.
Sodium	610 ppm.
Sulphate	464 ppm.
Chloride	730 ppm.
Salinity	1 200 ppm.

Table 4. Analysis of water from Keyvanieh well (Alborz, depth of about 200 m.)

Specific gravity	1.1
*p*H	7.0
Calcium	643 ppm.
Magnesium	387 ppm.
Sodium	5 248 ppm.
Sulphate	511 ppm.
Chloride	8 200 ppm.
Salinity	13 000 ppm.

Table 5. Analysis of water from Saradjeh water well no. 1. Taken from five horizons ranging from 30–210 m. in depth

Specific gravity	1.06
*p*H	7.6
Calcium	612 ppm.
Magnesium	268 ppm.
Sodium	2 750 ppm.
Sulphate	1 256 ppm.
Chloride	2 297 ppm.
Salinity	5 580 ppm.

In addition, nitrate bicarbonates, ammonium and iron radicals were also detected.

Table 6. Analysis of the water flowing out of Alborz no. 6 well when its depth was 10,840 ft. (3,304 m.)

Specific gravity	1.1
*p*H	6.2
Calcium	27 158 ppm.
Magnesium	1 559 ppm.
Iron	466 ppm.
Sodium	78 643 ppm.
Sulphate	626 ppm.
Chloride	200 000 ppm.
Salinity	203 000 ppm.

Table 7. Analysis of the water flowing out of Alborz no. 7 well when its depth was 10,194 ft. (3,107.13 m.)

Specific gravity	1.23
*p*H	5.3
Calcium	14–760 ppm.
Magnesium	1 049 ppm.
Iron	112 ppm.
Sodium	110 000 ppm.
Sulphate	125 ppm.
Chloride	205 000 ppm.
Salinity	279 500 ppm.

N.B. There was a considerable amount of suspended matter in this sample (about 150 gm./l. as against 2.10–4.60 gm./l. in samples from Alborz no. 6 well; this may account for the slightly higher specific gravity).

RÉSUMÉ

Étude de données géochimiques sur les eaux subsuperficielles de la région de Koum (J. Tavana)

L'auteur décrit différents types d'"échantillonneurs" d'eau, ainsi que les méthodes employées pour obtenir des échantillons d'eau de sept puits de la région de Koum. Il donne les résultats de l'analyse chimique de ces échantillons, et étudie la façon dont leur degré de salinité et leur composition chimique varient en fonction de la nature des roches et du sol, de la proximité de cours d'eau et de la présence de culots de sel.

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A COMPARISON OF SUBSOIL WATER CONDITIONS AND SALINITY IN THE SUDAN AND IRAQ

by

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Irrigation in the Sudan Gezira, in contrast to that in the central plains of Iraq, is historically very recent. The plains of Iraq have been irrigated in part and at times since the third millenium B.C. Irrigation started in the Sudan Gezira in 1912. The soils of the Gezira contained very large quantities of salt before irrigation began, and this salt, only slightly changed in distribution and amount, is still present. There has been no deterioration due to salinization, nor indeed to any other change. The basic reason why there has been no salinization of the upper soil is because the water table is deep and is not rising. This is a consequence of the low permeability of the Gezira soil; in Iraq the soils are more permeable and the water table is sharply influenced by irrigation, and there are many instances of a high water table having caused salinization of the upper soil. We stress the upper soil, because in both the Gezira and Iraq the lower soil from a depth of 1 to 2 m. is generally quite dangerously saline. If the Gezira soil were more permeable, that is to say in general terms if it were a better soil, the menace of a mounting water table would arise and since the subsoil is saline the consequences to agriculture would be disastrous. As it is there is sufficient downward movement of water to prevent the accumulation of salt and to keep the salts of the subsoil at a safe distance from the surface. Under the present regime there is not enough leaching to remove much salt from the profile root zone.

Direct comparison of the content and distribution of salt before irrigation started and at present is difficult to obtain. However, on the Gezira Research Farm at Wad Medani rotation experiments have for long been conducted which enable comparison to be made of land irrigated with different frequencies. Table 1 shows the salt contents measured down the profiles in 6-m. steps for four rotations. The experiment which includes these rotations started in 1932, the comparison was made in 1954.

TABLE 1. Salt distribution in Gezira soil under different rotations (percentage salt)

6-inch step	Rotation			
	C.C.C.C.[1]	C.F.[2]C.F.	C.F.F.C.	C.F.F.F.
1	0.09	0.09	0.08	0.09
2	0.11	0.09	0.08	0.10
3	0.11	0.09	0.09	0.11
4	0.13	0.10	0.10	0.10
5	0.15	0.12	0.14	0.22
6	0.35	0.24	0.49	0.41
7	0.61	0.40	0.56	0.67
8	0.58	0.47	0.50	0.54
9	0.45	0.46	0.49	0.53
10	0.46	0.51	0.50	0.41
11	0.69	0.57	0.51	0.40
12	0.78	0.60	0.56	0.40
Mean	0.37	0.30	0.34	0.33

1. C = Cotton
2. F = Fallow

It will be seen that there is little difference between the four rotations, and we conclude that irrigation with Blue Nile water is not causing the accumulation of salts in the upper profile, and that the downward movement of water is too slow to be causing net leaching in the top 2 m. of soil. It should be appreciated that irrigation of cotton goes on for only eight months, for in the months of April, May, June and July the land is unirrigated.

The results given above were of course obtained on a restricted area, but it was one entirely typical of the Gezira soil. They have been confirmed in other long-term rotation experiments on the research farm. There is one area on the research farm which has been under cotton for nearly 40 years; in parts of it the salt content of the profile has been reduced to very low values. The soil here was possibly more permeable originally, and more water has been able to pass through the profile during the annual irrigation period. In general, however, land under more normal wider rotations still has a profile with a relatively salt free upper soil resting upon a saline subsoil, as illustrated in Table 1. And although cotton grown continuously in the Gezira gives low yields, this is not an indication of a decline in basic fertility. Parts of this plot of annual cotton were recently fallowed for short periods, but when they reverted to cotton normal yields were obtained. The long period with irrigation every year had not damaged the soil.

The actual figures are of interest. The experiment used small sub-plots in four randomized blocks and the sub-plots were split for nitrogen (80 lb./acre applied as ammonium sulphate), and no nitrogen.

TABLE 2.

Treatment	Yield no nitrogen	Yield nitrogen
	lb./acre	lb./acre
C.C.C.C.C.[1]	600	1035
C.C.C.F.C.[1]	926	1257
C.C.F.F.C.[1]	1242	1482
C.F.F.F.C.[1]	1407	1521

1. Year of comparison

The following figures for exchangeable cations in Gezira soil may be compared with those for non-saline soils from the Lower Diyala area in Iraq. This is the area irrigated by water abstracted from the River Diyala at the barrage 60 miles north-east of Baghdad.

TABLE 3.

	Na	Ca	Mg	K	
Gezira	6	31	7	0.7	me.%
Diyala	1.2	10.5	4.5	1.1	me.%

In the conventional assessment based on the percentage of exchangeable sodium the Diyala soils would rank as superior to the Gezira soils. This is actually consistent with their higher permeabilities and other physical properties, for example their less ready dispersion. The physical state of Gezira soils deteriorates while under irrigation, and this, together with nutritional conditions, has imposed a wide rotation with much fallow upon Gezira agriculture. The nature of the soil has dictated a system with a low intensity of irrigation; its low permeability has combined with this to prevent any rise of the water table.

The Diyala soils are permeable enough to permit very considerable transmission losses, which have produced a high and fluctuating water table. A limit is, however, set to losses to the water table by an acute shortage of water in summer, and also by the use of a winter cropping system under which a piece of land is watered only every alternate winter.

We have studied the Lower Diyala irrigation in Iraq, including the water table levels and their changes. The area is of the same order as that of the Sudan Gezira. The salinity of the soil and the ground-water conditions differ, as we have shown above. The waters of the Nile and the Diyala are both satisfactory irrigation waters. The Diyala is, however, considerably more saline than the Nile. The general comparison of the Nile and Iraq rivers has been made by Smith [3].[1]

Table 4 gives the frequency of specified levels of the ground-water. They were obtained during a general survey of the ground-water carried out in 1957 during the month of April, at which period the levels are at their highest.

TABLE 4. Ground-water depths, Lower Diyala, April 1957 (depth in metres below ground level)

Depth range metres	Numbers of sites with range
0 –0.5	4
0.51–1.0	12
1.01–1.5	16
1.51–2.0	19
2.01–2.5	24
2.51–3.0	10
3.01–3.5	9
3.51–4.0	9
4.01–4.5	13
4.51–5.0	5
Greater than 5.0	78

The annual change in the ground-water level is illustrated in Table 5.

TABLE 5. Changes in water table levels, Lower Diyala, 1956–57 (mean values for 17 sites, depth in cm. below ground level)

Date	Depth	Date	Depth
4. 11. 56	271	15. 5. 57	109
16. 11. 56	264	18. 6. 57	142
15. 12. 56	256	16. 7. 57	185
20. 1. 57	213	6. 8. 57	217
2. 2. 57	205	15. 8. 57	207
19. 2. 57	191	1. 9. 57	227
2. 3. 57	167	15. 9. 57	215
16. 3. 57	120	30. 9. 57	215
31. 3. 57	123	31. 10. 57	225

The rise during the first half of the year follows the beginning and the development of winter irrigation. The fall which follows is associated with a very large reduction of irrigation in summer. It is evident that the Lower Diyala has some natural drainage which under the present regime deals with the water which reaches the water table on an annual basis, but only if one accepts as tolerable the high levels reached during April and May. There

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[1] The figures in brackets refer to the bibliography on page 60.

are other irrigated areas in Iraq where the salinity and ground-water situations are worse than in the Diyala area.

In the light of these figures for ground-water levels it is not surprising that the Lower Diyala has considerable areas of highly saline soil. The extent of this salinity may be judged from our recent soil survey, when we found the following areas of soils:

(1) Non-saline or slightly saline, 580,000 acres.
(2) Moderately saline, 150,000 acres.
(3) Saline and highly saline, 180,000 acres.

The values of the electrical conductivity of the saturated extracts corresponding to these three salinity classes are:

(1) E.C. < 8.0 mmhos./cm.
(2) E.C. 8.0–15.0 mmhos./cm.
(3) E.C. > 15.0 mmhos./cm.

In Table 6 the actual mean salt contents are given for these three categories of salinity.

TABLE 6. Salt contents of three categories of Lower Diyala soils (percentage salt)

Depth cm.	Non-saline, slightly saline	Moderately saline	Saline and highly saline
0–50	0.07	0.27	0.76
51–100	0.10	0.33	0.65
101–150	0.13	0.36	0.56

These figures may be compared with those for Gezira soil given in Table 1. It will be noticed that Gezira soil is highly saline in its deeper layers; the means given in Table 6 obscure the fact that many individual Diyala soils have similar salt distributions. In comparing the two soils it is also necessary to realize that the soluble salts in Gezira soil are principally sulphate; Diyala soils all contain chlorides as well as sulphates.

The present situation in the Diyala area, with parts too saline for economic cropping and with areas of high water tables, is not satisfactory. Large areas remain, however, under effective cultivation, and we have here an irrigated area with a rough equilibrium between natural drainage and the losses to the water table—the price of this survival is a low cropping intensity as in the Gezira.

The salinity of the subsoil water in the Lower Diyala varies over a very large range. Table 7 illustrates this.

On the upper reaches of the Diyala river a storage dam is being built at Derbendi Khan, and it is expected that the irrigation water available for the Lower Diyala area will be doubled within a short time. It is of course obvious that this cannot be done without installing an effective drainage scheme. In this connexion we recognize that the permeability of the soils of the Lower Diyala, which permit excessive losses, will also make drainage feasible. It is the involuntary and unnecessary losses of water to the water table that produce the high water table of the Diyala area. The irrigation water is of medium salinity and the necessary leaching water for the prevention of salt accumulation could be dealt with by natural drainage.

A drainage installation would be of benefit under the existing regime; it will be essential when greatly increased water is available. Our economic studies show that when combined with the necessary drainage system increased irrigation and improved methods will result in large increases in productivity which will justify the large sums required for the engineering works.

The two areas we have been discussing—the Sudan Gezira and the Lower Diyala in Iraq—both have low cropping intensities. In the main Gezira rotation 45 per cent of the area is cropped each year, while in the Lower Diyala this percentage is about 55. Both areas avoid the necessity of artificial drainage—the Lower Diyala by a narrow margin and at the cost of considerable salinization. They are examples of irrigation without artificial drainage, but they both use an agricultural system with a large proportion of fallow land.

TABLE 7. Ground-water salinities, Lower Diyala, April 1957 (E.C. in mmhos./cm. at 25° C)

Salinity range	No. of samples	Salinity range	No. of samples	Salinity range	No. of samples
0–2.0	16	16.1–18.0	5	32.1–34.0	5
2.1–4.0	15	18.1–20.0	2	34.1–36.0	3
4.1–6.0	5	20.1–22.0	5	36.1–38.0	4
6.1–8.0	5	22.1–24.0	4	38.1–40.0	2
8.1–10.0	8	24.1–26.0	3	40.1–42.0	3
10.1–12.0	3	26.1–28.0	2	42.1–44.0	2
12.1–14.0	8	28.1–30.0	6	Greater than 44.0	12
14.1–16.0	4	30.1–32.0	1		

It will be noticed that a proportion of the subsoil waters are of relatively low salinity. Sites where the salinity is low tend to be near large canals. It seems probable that long-continued natural drainage has gradually reduced the salinity of the ground-waters. This is what one hopes will be the consequence of any drainage system in a saline area. We have no knowledge of how long this process takes, for as has been said above there is a long history of irrigation in the Lower Diyala, and the main canals have occupied their present positions for many hundreds of years.

RÉSUMÉ

Étude comparative de l'état et de la salinité des eaux souterraines au Soudan et en Irak (T. N. Jewitt)

La comparaison porte essentiellement sur la Djezireh soudanaise et les plaines mésopotamiennes de l'Irak. L'eau utilisée au Soudan pour l'irrigation a une salinité totale plus faible que l'eau du Tigre, bien qu'elle contienne une proportion de sodium sensiblement plus forte. En ce qui concerne les sols, celui de la Djezireh est plus alcalin, de grain plus fin et plus riche en sodium échangeable que ceux de l'Irak; d'autre part, on n'y trouve pas, comme c'est le cas en Irak, de grandes quantités de CO_3Ca finement divisé.

Comme le laisse prévoir sa composition, le sol de la Djezireh est moins perméable que ceux de la plaine irakienne, ce qui se traduit par une faible déperdition d'eau dans les canaux et l'existence d'une nappe aquifère profonde sur laquelle l'irrigation n'a pas d'effets. En Irak, au contraire, la déperdition est importante et l'irrigation entraîne à bref délai une élévation dangereuse du niveau hydrostatique.

Pour pouvoir pratiquer l'irrigation de manière continue au Soudan, il faut donc veiller à ce que les sels demeurent en profondeur; l'eau doit descendre assez lentement pour qu'au total la couche où se trouvent les racines perde au moins autant de sels que l'irrigation en apporte. En Irak, où les sols sont plus perméables et la percolation d'eau très forte, il est nécessaire d'avoir recours à un système de drainage artificiel.

La différence fondamentale entre les deux régions considérées tient à l'importance de la déperdition d'eau dans les canaux et tranchées: quand cette déperdition est faible, comme au Soudan, il suffit que la percolation soit assez réduite pour que le niveau hydrostatique ne monte pas. Mais en Irak, où la propagation rapide de l'eau dans le sol n'est pas compensée par un drainage naturel, on doit assurer un drainage artificiel pour empêcher la montée des eaux salines du sous-sol.

DISCUSSION

C. A. Bower. (1) What is the salinity of the Sudan water?

(2) Did I understand you to say that you do not think salinity will become a problem in the Sudan situation owing to the low permeability of the soil?

T. Jewitt. (1) The water has about 150 ppm. dissolved salts; from the point of view of the calcium to sodium ratio it is a fairly satisfactory irrigation water.

(2) The low permeability with associated low leaching will prevent the rise of the subsoil water, thus preventing salinization from below. We believe, however, that the downward movement of water does suffice to prevent the accumulation of the salts contained in the irrigation waters.

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L'INTERPRÉTATION DES ANALYSES CHIMIQUES DES EAUX SALÉES

par
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La composition chimique des eaux souterraines et superficielles répond aux types les plus variés. Ces types ont tendance à se grouper en zones climatériques, géologiques, hydrologiques [2, 3, 4, 5, 6, 7, 9, 11, 12, 13, 14, 15, 19][1].

La composition chimique varie ainsi d'une zone à une autre. Il s'agit de comprendre les causes de ce fait.

Il y a des causes lithologiques, qui dépendent de la composition chimique de l'aquifère et également du toit et du mur. Ce sont celles qui correspondent en particulier aux zonalités géologiques [6, 7, 11, 12, 13, 14].

La concentration par dissolution représente une autre cause, le facteur temps de contact entrant alors en jeu. Les eaux se concentrent d'autant plus par dilution que le trajet de circulation est plus long et plus lent. C'est ce qui intervient dans la zonalité hydrologique et dans la zonalité de profondeur[2] [6, 12, 13, 14].

Enfin intervient la concentration par évaporation. C'est la cause principale de la zonalité climatérique [6, 11].

En définitive, si les causes lithologiques sont le facteur initial du faciès de la composition chimique, le facteur final et essentiel est la concentration. Autant, au début, la composition chimique des eaux est fort diverse, en fonction des conditions lithologiques et des facteurs d'attaque des roches, autant, par la suite, au cours de son évolution par concentration, cette composition tend à s'uniformiser et à prendre le faciès de l'eau de mer [6].

Pour connaître l'origine des divers faciès des eaux, il est indispensable de comparer les différentes compositions chimiques entre elles. Encore faut-il en choisir le moyen d'une telle comparaison. Une comparaison visuelle de la représentation d'une composition chimique est plus rapide et permet mieux que l'examen d'une série de chiffres de saisir, d'un seul coup d'œil, rapports et différences.

Aussi avons-nous, depuis longtemps déjà, proposé à cet effet [8, 10, 18], les diagrammes semi-logarithmiques, lesquels, par la suite, ont été utilisés dans les services hydrogéologiques d'Afrique du Nord, d'Afrique occidentale et par plusieurs compagnies de recherches pétrolières.

Il nous a paru utile d'exposer ici notre méthode de façon plus détaillée.

Mais je voudrais, dès maintenant, insister sur un point fondamental: à savoir qu'aucune interprétation, aucune comparaison des analyses chimiques ne peut se faire en réduisant les éléments en pourcentages du total du résidu sec, car on ne tient alors compte ni des valeurs absolues indispensables, ni du fait que la solubilité de certains éléments est plus limitée que celle d'autres. On risque d'aboutir ainsi à des erreurs considérables.

DIAGRAMME SEMI-LOGARITHMIQUE SCHOELLER

Les diagrammes semi-logarithmiques présentent sur les autres diagrammes les avantages suivants:

On peut porter sur un même graphique plusieurs eaux, car les tracés sont moins enchevêtrés que dans le cas où les éléments ont été réduits en pourcentages de la concentration totale.

Les graphiques représentent non seulement les valeurs relatives, mais également les valeurs absolues, dont certaines sont extrêmement importantes.

On lit immédiatement les rapports des éléments entre eux. Et d'un seul coup d'œil on voit si les rapports entre deux éléments dans les eaux à comparer sont égaux, ce qui ne peut se faire avec un graphique arithmétique. Le graphique semi-logarithmique évite le travail fastidieux du calcul des milliéquivalents.

Enfin il peut indiquer, d'une manière très simple, si le produit de solubilité de tel ou tel composé chimique est atteint.

Construction

La construction d'un diagramme semi-logarithmique est très simple.

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[1] Les numéros entre crochets renvoient à la bibliographie, p. 70.

[2] Je considère la zonalité de profondeur comme un cas particulier de la zonalité hydrologique.

Le long de l'axe des x (fig. 1) on porte, à intervalles égaux, le symbole des ions ou radicaux[1]. L'ordre ne doit pas être quelconque, de manière à faciliter les comparaisons des rapports principaux et la détermination des produits de solubilité. Or il se trouve que cet ordre peut être chimiquement logique, comme celui que j'ai établi en 1934:

$$r\mathrm{Ca} \quad r\mathrm{Mg} \quad r\mathrm{Na} + r\mathrm{K} \quad r\mathrm{Cl} \quad r\mathrm{SO_4} \quad r\mathrm{HCO_3}$$

Il permet d'avoir côte à côte $r\mathrm{Ca}$ et $r\mathrm{Mg}$, $r\mathrm{Cl}$ et $r\mathrm{SO_4}$, enfin $r\mathrm{Na} + r\mathrm{K}$ et $r\mathrm{Cl}$, et par conséquent de lire directement sur le graphique les rapports cardinaux $r\mathrm{Mg}/r\mathrm{Ca}$ et $r\mathrm{SO_4}/r\mathrm{Cl}$, ainsi que l'indice de déséquilibre chlore-alcalin $\frac{r\mathrm{Cl} - r\mathrm{Na} - r\mathrm{K}}{r\mathrm{Cl}}$ particulièrement important à considérer dans les échanges de bases.

L'élément relativement constant $r\mathrm{HCO_3}$ est placé à une extrémité du graphique, qui devient ainsi plus clair.

Cet ordre est logique. En effet, les éléments sont disposés symétriquement, selon un ordre chimique par rapport à un axe vertical placé entre $r\mathrm{Cl}$ et $r\mathrm{Na}$.

Le long de l'axe des y, on porte le nombre des milliéquivalents de chacun des éléments. Le report peut se faire de plusieurs manières sur le papier semi-logarithmique; soit en calculant le nombre de milliéquivalents à partir des poids donnés par l'analyse; soit à l'aide d'une sorte de règle à calcul qu'on peut fabriquer soi-même. Pour cela on découpe dans un papier semi-logarithmique de même module que celui du graphique, une bande logarithmique étroite sur laquelle on a porté le Ca à la division 20, le Mg, à 12, le Na, à 23, le Cl, à 35,5, le $\mathrm{SO_4}$, à 48, le $\mathrm{HCO_3}$, à 61, ou le $\mathrm{CO_3}$ combiné, à 30.

Pour reporter les éléments de l'analyse, donnés en poids, on fait coïncider l'élément considéré, marqué sur l'échelle, avec la division 1 du graphique. Puis, sur la même échelle, on note le point correspondant du poids en milligrammes dudit élément. On porte alors sur le graphique, juste en face de ce point, l'emplacement de l'élément. Par exemple, si l'on veut porter Ca = 240 mg sur le graphique, on place le repère Ca = 20 de l'échelle sur le 1 du graphique. Puis on considère le point 240 de l'échelle. En face de ce point et coïncidant avec lui, on porte sur le graphique l'emplacement du point $r\mathrm{Ca} = 240/20$. Ce travail est extrêmement simple et rapide, et permet d'utiliser n'importe quel papier semi-logarithmique du commerce.

On peut à l'avance établir un papier semi-logarithmique dont les ordonnées de chacun des éléments Ca, Mg, Na, Cl, $\mathrm{SO_4}$, $\mathrm{HCO_3}$ sont décalées d'une valeur respectivement égale à 20, 12, 23, 35,5, 48 et 61. De la sorte on peut porter directement sur les échelles individuelles les poids en milligrammes fournis par les analyses. On laisse à droite et à gauche du graphique la division originale qui donnera le nombre de milliéquivalents. Cela est pratique lorsqu'on a un très grand nombre de graphiques à exécuter, par exemple dans un service hydrogéologique, où l'on peut se permettre de faire imprimer ou tirer ces feuilles.

Dans ce cas cependant, le calcul des rapports en milliéquivalents, et celui des produits de solubilité, demandent un travail supplémentaire, si l'on ne veut pas surcharger le graphique.

De toute manière, on a intérêt à ce que la disposition des graphiques demeure aussi simple que possible; on doit éviter les surcharges. Qualité fondamentale de tels graphiques: la lecture doit en être aisée et rapide.

Lecture des rapports

Le grand avantage des diagrammes semi-logarithmiques est qu'ils permettent de comparer immédiatement les rapports existant entre les éléments de chaque eau avec ceux des eaux voisines, ce qu'on ne peut faire avec les diagrammes arithmétiques.

Soit une eau ayant des concentrations $r\mathrm{Ca}$ et $r\mathrm{Mg}$ et une autre ayant des concentrations $r'\mathrm{Ca}$ et $r'\mathrm{Mg}$. Si la droite réunissant $r\mathrm{Ca}$ et $r\mathrm{Mg}$ est parallèle à la droite $r'\mathrm{Ca}$ et $r'\mathrm{Mg}$, les rapports $r\mathrm{Mg}/r\mathrm{Ca}$ et $r'\mathrm{Mg}/r'\mathrm{Ca}$ sont égaux. On a en effet par construction

$$\log r\mathrm{Mg} - \log r\mathrm{Ca} = \log r'\mathrm{Mg} - \log r'\mathrm{Ca} = \log r\mathrm{Mg}/r\mathrm{Ca} = \log r'\mathrm{Mg}/r'\mathrm{Ca}.$$

C'est là un des éléments majeurs d'appréciation; ces diagrammes le fournissent. Les rapports principaux à considérer sont:

$$r\mathrm{Mg}/r\mathrm{Ca} \qquad r\mathrm{SO_4}/r\mathrm{Cl} \qquad \frac{r\mathrm{Cl} - r\mathrm{Na} - r\mathrm{K}}{r\mathrm{Cl}}$$

$$\frac{r\mathrm{Na}}{r\mathrm{Ca} + r\mathrm{Mg}} \qquad \frac{r\mathrm{Na}}{r\mathrm{Ca}} \qquad \frac{r\mathrm{Na}}{r\mathrm{Mg}}$$

Lecture des produits de solubilité

La lecture des produits de solubilité est de première importance; elle permet de saisir les causes de l'évolution de la composition chimique des eaux superficielles et des eaux souterraines.

Saturation en $CaSO_4$. Supposons qu'on ait à comparer le produit $[\mathrm{SO_4}]\,[\mathrm{Ca}]$ d'une eau, au produit de solubilité du sulfate de calcium $[\mathrm{SO_4}]\,[\mathrm{Ca}] = \mathrm{K_{SO_4Ca}}$

Le produit de solubilité est calculé en multipliant les concentrations en moles de $\mathrm{SO_4}$ et de Ca. Si l'on opère en multipliant les milliéquivalents, on a alors:

$$(r\mathrm{SO_4})\ (r\mathrm{Ca}) = 4\ \mathrm{K_{SO_4}} \times 10^6$$

Traçons d'abord sur le graphique une verticale, à mi-chemin entre $r\mathrm{SO_4}$ et $r\mathrm{Ca}$. Portons sur cette verticale

$$2 \times 10^3 \sqrt{\mathrm{K_{SO_4}}} = \sqrt{(r\ \mathrm{SO_4})\ (r\mathrm{Ca})}$$

qui se trouvera en un point S_0 représentant le produit de solubilité. L'ordonnée de ce point S_0 est donc

$$\log \sqrt{(r\mathrm{SO_4})\ (r\mathrm{Ca})} = \tfrac{1}{2}\ (\log\ (r\mathrm{SO_4}) + \log\ (r\mathrm{Ca}))$$

---

[1] *r* indique qu'il s'agit de milliéquivalents.

Maintenant joignons r'Ca et $r'SO_4$ de l'eau, par une droite qui coupera la verticale S_0 en un point S' tel qu'on a par construction:

$$\tfrac{1}{2} (\log (r'SO_4) + \log (r'Ca)) = \log S'$$

d'où

$$S' = \sqrt{(r'SO_4)\,(r'Ca)}$$

On voit, dès lors, que si le point S' coïncide avec le point S_0, l'eau est saturée en $CaSO_4$.

Si le point S' est situé au-dessus de S_0, l'eau est sursaturée en $CaSO_4$.

Si le point S' est situé en dessous de S_0, l'eau est susceptible de dissoudre encore du $CaSO_4$.

Mais on sait que le produit de solubilité dépend à la fois de la force ionique μ de la solution et de la température de celle-ci.

Dans le tableau ci-dessous nous donnons les variations du produit de solubilité de $CaSO_4$ en fonction de la température et de la concentration en NaCl, avec la force ionique correspondante.

TABLEAU 1. Solubilité de $CaSO_4, 2H_2O$

NaCl	$CaSO_4$		Force ionique μ	
	à 14°	à 20°	à 14°	à 20°
milli-équivalents	milli-équivalents	milli-équivalents		
0	25	31	0,050	0,062
50	34	40	0,118	0,130
100	41	46	0,182	0,192
200	50	55	0,300	0,210
250	54	59	0,358	0,368
500	65	69	0,650	0,638
1000	84	88	1,168	1,176
1500	97	101	1,694	1,702
1750	101	105	1,952	1,960
2000	104	107	2,208	2,214
2250	106	107	2,462	2,464
2500	104	105	2,708	2,710
2750	103	103	2,956	2,958
3000	100	100	3,200	3,200
3500	93	93	3,686	3,686
4000	87	87	4,174	4,174
4500	81	81	4,662	4,662
5000	78	78	5,156	5,156

Valeurs à ajouter à S'_0 de $CaSO_4$ pour les différentes températures, à $\mu = 0$.

Températures	0	10°	20°	30°	40°	55°	60°
$\Delta' S_0$	—3,8	—1,3	0	1,2	1,6	1,0	0

Il s'agit donc de déplacer le point S de la verticale en fonction de la force ionique de la solution.

La force ionique μ, rappelons-le, est la demi-somme de la molalité stœchiométrique de chaque ion, multipliée par le carré de sa valence. Soit C la concentration molale, c'est-à-dire le nombre de moles dans 1 kg d'eau, Z la valence de l'ion:

$$\mu = \tfrac{1}{2} [C_1Z_1^2 + C_2Z_2^2 + \ldots C_nZ_n^2]$$

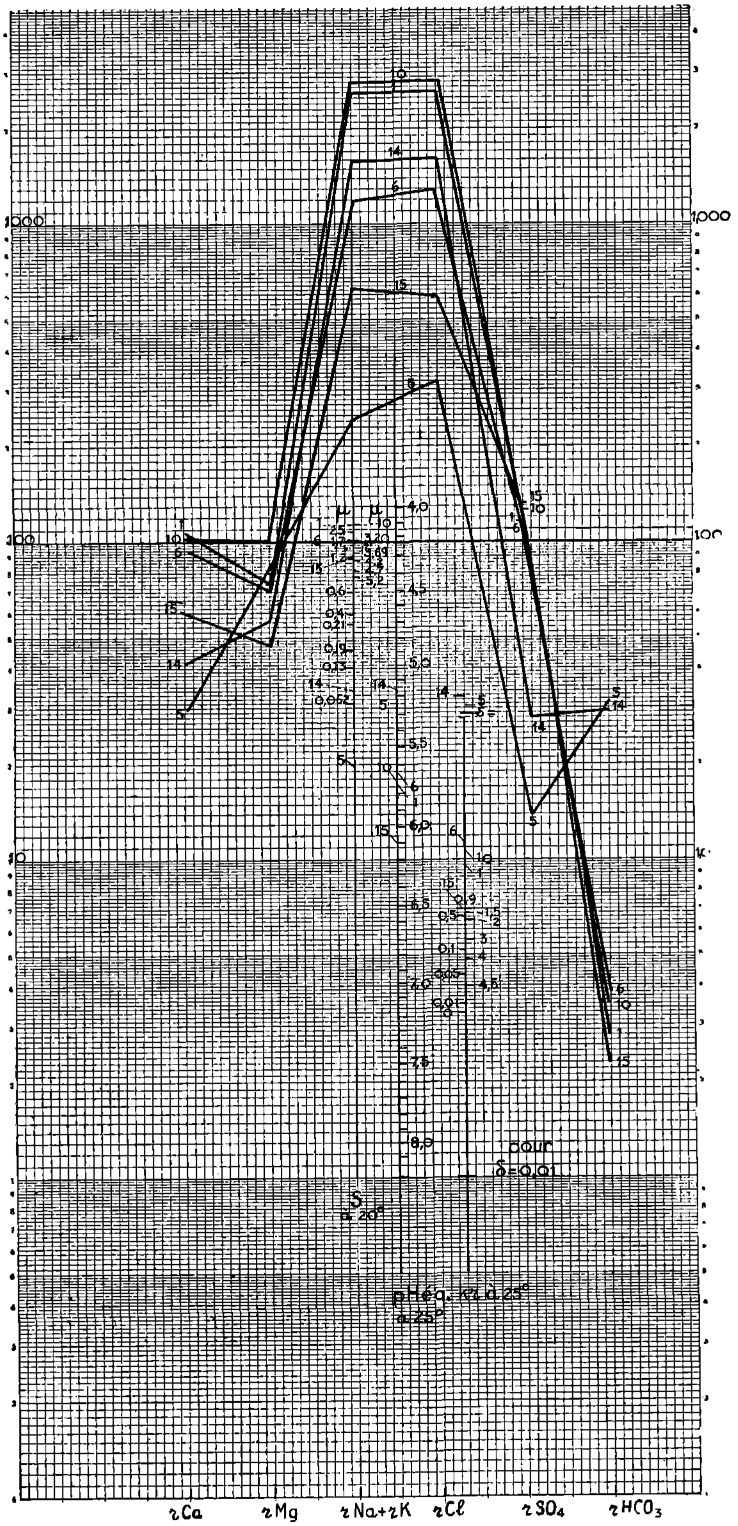

FIG. 1. Exemple de diagramme semi-logarithmique. ("Eaux du West Texas", *Analyses in Problems of Petroleum Geology*, 1934, p. 883–884.)
S = échelle des produits (rSO_4) $(r$Ca) pour différentes forces ioniques à 20°; *p*H éq. = échelle des *p*H d'équilibre de la solubilité du $CaCO_3$ à 25°; k_r = échelle des k_r à 25° pour diverses forces ioniques.

Si pour calculer la force ionique on utilise les milliéquivalents r, on a donc, puisque $r = \mathrm{C} \cdot \mathrm{Z} \times 10^3$:

$$\mu = \tfrac{1}{2}\,[r_1 Z_1 + r_2 Z_2 + \ldots r_n Z_n] \times 10^3$$

Ainsi la force ionique d'une eau ayant:

$r\mathrm{Ca} = 10 \quad r\mathrm{Mg} = 6 \quad r\mathrm{Na} = 12 \quad r\mathrm{Cl} = 13 \quad r\mathrm{SO_4} = 9$
$r\mathrm{HCO_3} = 6$

sera:

$$\mu = \tfrac{1}{2}\,[10 \times 2 + 6 \times 2 + 12 \times 1 + 13 \times 1 + 9 \times 2 + 6] \times 10^{-3}$$

$$\mu = 40{,}5 \times 10^{-3}$$

Pour placer le point S_0 de comparaison sur la verticale. on calculera donc la force ionique de la solution de la manière indiquée ci-dessus, en tenant compte des milliéquivalents de tous les ions. Et l'on supposera, à titre d'approximation, que cette force ionique a le même effet que celle qui résulte des deux sels SO_4Ca et NaCl et qui est donnée dans le tableau précédent.

On aura avantage à construire à l'avance une échelle des points S_0 en fonction de la force ionique et de la température, et à la rendre mobile, comme c'est le cas de l'échelle de la figure 2, nº 1.

L'échelle porte les points S_0 correspondant aux diverses forces ioniques. En bas de l'échelle se trouvent les valeurs de corrections à opérer en raison de la température.

Lorsque l'eau est à la température $\theta = 20°$, on porte le trait $\theta = 20°$ sur l'ordonnée 1 du papier semi-logarithmique. Sur cette échelle, on repère le point S_0 donné par la force ionique, puis on le reporte en face sur le graphique et on le compare avec le point S' de l'eau.

Saturation en $CaCO_3$. La teneur en $CaCO_3$ d'une eau dépend du produit de solubilité $[CO_3]\,[Ca] = Kc$, et de la tension δ du CO_2 gazeux de l'atmosphère en contact avec l'eau, c'est-à-dire aussi de la concentration en CO_2 dissous dans l'eau, que nous représentons par $[H_2CO_3]$.

Des équations suivantes représentant les divers équilibres:

$$[H_2CO_3] = \frac{a\delta}{22{,}4} \qquad (1)$$

$$\frac{\langle H^+\rangle\,[HCO_3^-]}{[H_2CO_3]} = K_1''' \qquad (2)$$

$$\frac{\langle H^+\rangle\,[CO_3]}{[HCO_3^-]} = K_2''' \qquad (3)$$

$$[CO_3]\,[Ca^{++}] = K'c \qquad (4)$$

$$\langle H^+\rangle\,\langle OH^-\rangle = K_{H_2O} \qquad (5)$$

dans lesquelles:

a représente le coefficient de solubilité H_2CO_3 dans une solution de force ionique μ.
[ ], les concentrations molales;
⟨ ⟩, les concentrations des activités;

on tire:

$$[HCO_3^-]^2\,[Ca^{++}] = [H_2CO_3] \Big/ \frac{K_2'''}{K_1'''\ K'c} = \frac{a\delta}{22{,}4} \Big/ \frac{K_2'''}{K_1'''\ K'c}$$

Comme

$$(r\mathrm{HCO_3^-}) = [HCO_3^-] \times 10^3$$
$$(r\mathrm{Ca}) = 2\,[Ca^{++}] \times 10^3$$

on a avec Kr représentant la racine cubique:

$$\mathrm{Kr} = \sqrt[3]{(2\ \mathrm{MCO_3})^2\,(2\ \mathrm{Ca})} = \sqrt[3]{2\,[H_2CO_3] \Big/ \frac{K_2'''}{K_1'''\ K'c}} \times 10$$

$$\mathrm{Kr} = \sqrt[3]{\frac{a\delta}{22{,}4} \Big/ \frac{K_2'''}{K_1'''\ K'c}} \times 10^3$$

La valeur de Kr est donc fonction de la concentration en CO_2 libre dissous dans l'eau $[H_2CO_3]$, ou de la tension δ du CO_2.

Traçons à présent sur le graphique semi-logarithmique, entre rCa et $r\mathrm{HCO_3^-}$, une verticale placée à ⅓ de chemin de $r\mathrm{HCO_3^-}$ et à ⅔ de chemin de rCa. Portons sur cette verticale le point Kr précédent, correspondant à la valeur de H_2CO_3 ou de δ. Joignons ensuite les points $r'\mathrm{HCO_3}$ et r'Ca de l'eau, par une droite qui coupera l'axe des Kr en un point K'r. Par construction on a:

$$\log \mathrm{K'r} = \tfrac{1}{3}\,[2 \log r'\mathrm{HCO_3} + \log r'\mathrm{Ca}]$$

$$\text{d'où } \mathrm{K'r} = \sqrt[3]{(r'\mathrm{HCO_3})\ 2\ (r'\mathrm{Ca})}$$

Dès lors on voit que:

a) si le point K'r coïncide avec Kr, l'eau est saturée en $CaCO_3$,
b) si K'r est situé au-dessus de Kr, l'eau est sursaturée, et
c) si K'r est situé en dessous de Kr, l'eau peut encore dissoudre du $CaCO_3$.

Comme nous l'avons précédemment fait remarquer, dans la majorité des cas l'eau est saturée en $CaCO_3$. Le point K'r donne alors la valeur du CO_2 libre dissous dans l'eau, ou la tension δ de l'atmosphère surmontant l'eau.

Cette valeur K'r est donc de première importance dans l'étude des résultats des analyses d'eau.

La position du point K'r dépend de la force ionique μ et de la température θ de la solution. En effet, $\dfrac{K_2'}{K_1'\ K'c}$ varie avec μ et θ.

Les formules suivantes, applicables à des valeurs de μ allant jusqu'à 0,8, donnent des valeurs approchées pour la température de 20°:

$$\log \frac{K_2'}{K_1'\,K'c} = 4{,}61 + 0{,}6\,\sqrt{\mu} - \frac{4{,}94\,\sqrt{\mu}}{1 + 1{,}61\,\sqrt{\mu}}$$

$$\log \frac{K_2'}{K_1'\,K'c} = 4{,}61 + 0{,}29\,\sqrt{\mu} - \frac{4{,}94\,\sqrt{\mu} + 0{,}52}{1 + 1{,}61\,\sqrt{\mu}}$$

On peut admettre que $\log \dfrac{K_2'}{K_1'\,K'c}$ augmente de 0,012 pour chaque degré d'élévation de température entre 0 et 30°.

Voici les valeurs de Kr à 25°, pour $\delta = 0{,}01$, calculées d'après les données de Cameron et Seidl:

TABLEAU 2.

NaCl	μ	Kr*
g/l		
0,000	0,002	3,32
9,720	0,17	5,62
21,010	0,37	6,53
30,301	0,53	6,84
50,620	0,88	7,14
69,310	1,2	7,04
98,400	1,7	6,88
147,40	2,54	6,27
234,50	4,043	5,60
262,30	4,52	3,88

* log Kr diminue de 0,004 par degré d'élévation de température.

A partir de ces données, on peut construire une échelle des Kr en fonction de la tension pour $\mu = 0$ et $\theta = 25°$. Comme on a Kr = 3,32 pour $\delta = 0{,}01$, on a donc la relation $\mathrm{Kr} = 15{,}4\sqrt{\delta^3}$ qui permet d'établir ce qui suit.

Nous portons en 1 de l'échelle $\delta = 0{,}01$ (fig. 2, n° 3). En 3,32 de l'échelle nous portons 0. Puis nous établissons les différentes tensions $\delta = 0{,}001$, $\delta = 0{,}1$, $\delta = 1$ et les graduations intermédiaires. La graduation est logarithmique et le module de cette graduation est le tiers de celui de l'échelle. Entre $\delta = 0{,}001$ et $\delta = 1$, il y a la même distance qu'entre 1 et 10 de l'échelle.

Pour tenir compte des variations de Kr en fonction de μ, nous avons porté au-dessus de 0 différentes valeurs de μ, permettant les décalages. Pour tenir compte des variations de température, nous avons porté différentes températures sur le côté de l'échelle.

Pour utiliser l'échelle, on procède de la manière suivante: on joint $r\mathrm{HCO_3}$ et $r\mathrm{Ca}$ de l'eau, par une droite qui coupe l'axe des Kr en un point K'r. Si l'eau a une force ionique $\mu = 0{,}01$, on place le $\mu = 0{,}01$, de l'échelle, en regard du K'r du graphique. Puis on lit sur l'échelle la tension δ, située en regard de l'ordonnée 1 du graphique. Cette tension est celle du CO_2 de l'eau. Pour tenir compte de la température on se sert des écarts placés sur le côté. Il est parfois bon de comparer les valeurs de K'r des différentes eaux. Mais pour que cette comparaison soit valable, on ramène toutes les valeurs à $\mu = 0$. Pour cela, comme précédemment, on place le μ de l'eau indiqué sur l'échelle, en face de K'r du graphique. Puis, en regard de $\mu = 0$ de l'échelle, on place sur le graphique le K'r $\mu = 0$ (ou $\mathrm{K'r_0}$).

On peut également étudier le degré de saturation du $CaCO_3$ dans l'eau, d'après le pH. On compare le pH de l'eau avec le pH d'équilibre, c'est-à-dire avec le pH correspondant à la saturation.

En effet, les équations précédentes conduisent à la formule:

$$p\mathrm{H\ eq} = \log \frac{\mathrm{K'c}}{\mathrm{K_2'''}} - \log\,[\mathrm{HCO_3^-}] - \log\,[\mathrm{Ca^{++}}]$$

Plaçons à mi-chemin de $r\mathrm{HCO_3}$ et de $r\mathrm{Ca}$ une verticale sur laquelle sont inscrits des points S correspondant aux divers pH d'équilibre, ce qui est possible puisqu'on a:

$$\log\,(r\mathrm{Ca}) + \log\,(r\mathrm{HCO_3}) = 2 \log \mathrm{S}$$

Si donc la droite joignant $r'\mathrm{Ca}$ et $r'\mathrm{HCO_3}$ d'une eau coupe la verticale en un point S' indiquant un pH d'équilibre inférieur à celui de l'eau, l'eau est sursaturée en $CaCO_3$. Si au contraire ce point S' indique un pH d'équilibre supérieur à celui de l'eau, l'eau est dite "agressive". La différence pH eq$-p$H eau donne une bonne mesure de l'agressivité. Mais, ici aussi, il y a lieu de tenir compte des corrections à faire, en fonction de la température et de la force ionique. Ces corrections sont indiquées dans le tableau suivant qui donne les valeurs ΔpH à ajouter au pH d'équilibre, en fonction de la force ionique μ, et les valeurs ΔpH à ajouter en fonction de la température θ de l'eau.

$$\Delta p\mathrm{H} = 3{,}618\sqrt{\mu}$$

μ	ΔpH	μ	ΔpH	θ	ΔpH	θ	ΔpH
0,001	0,12	0,014	0,44	0°	+ 0,50	16°	+ 0,18
0,002	0,16	0,015	0,45	1°	+ 0,48	18°	+ 0,16
0,003	0,20	0,016	0,47	2°	+ 0,46	18°	+ 0,14
0,004	0,23	0,017	0,48	3°	+ 0,44	19°	+ 0,12
0,005	0,26	0,018	0,49	4°	+ 0,42	20°	+ 0,10
0,006	0,28	0,019	0,51	5°	+ 0,40	21°	+ 0,08
0,007	0,31	0,020	0,52	9°	+ 0,38	22°	+ 0,06
0,008	0,33	0,021	0,53	7°	+ 0,36	23°	+ 0,04
0,009	0,35	0,022	0,55	8°	+ 0,34	24°	+ 0,02
0,010	0,37	0,023	0,56	9°	+ 0,32	25°	+ 0,00
0,011	0,39	0,024	0,57	10°	+ 0,30	26°	— 0,02
0,012	0,40	0,025	0,58	11°	+ 0,28	27°	— 0,04
0,013	0,42			12°	+ 0,26	28°	— 0,06
				13°	+ 0,24	29°	— 0,08
				14°	+ 0,22	30°	— 0,10
				15°	+ 0,20		

Pour faciliter le travail, nous pouvons, comme précédemment, construire une échelle mobile des divers pH d'équilibre (fig. 2, n° 4). La base de l'échelle porte les ΔpH en fonction de la force ionique μ, pour la température de 25°.

Par la droite $r'\mathrm{HCO_3}$ — $r'\mathrm{Ca}$ on a donc recoupé l'échelle des pH en un point S', où l'on indique le pH de l'eau. Puis on place le trait de la base de l'échelle correspondant à la force ionique de l'eau, en regard de la base 1 du graphique.

Enfin on lit sur l'échelle le pH situé en regard de S' du graphique. Ce pH, augmenté de la correction ΔpH pour la température, donne le pH d'équilibre de l'eau.

Les procédés que nous venons d'indiquer sont d'une utilisation extrêmement simple, malgré leur apparente complexité. Il suffit de très peu de temps pour se familiariser avec eux et s'en rendre complètement maître.

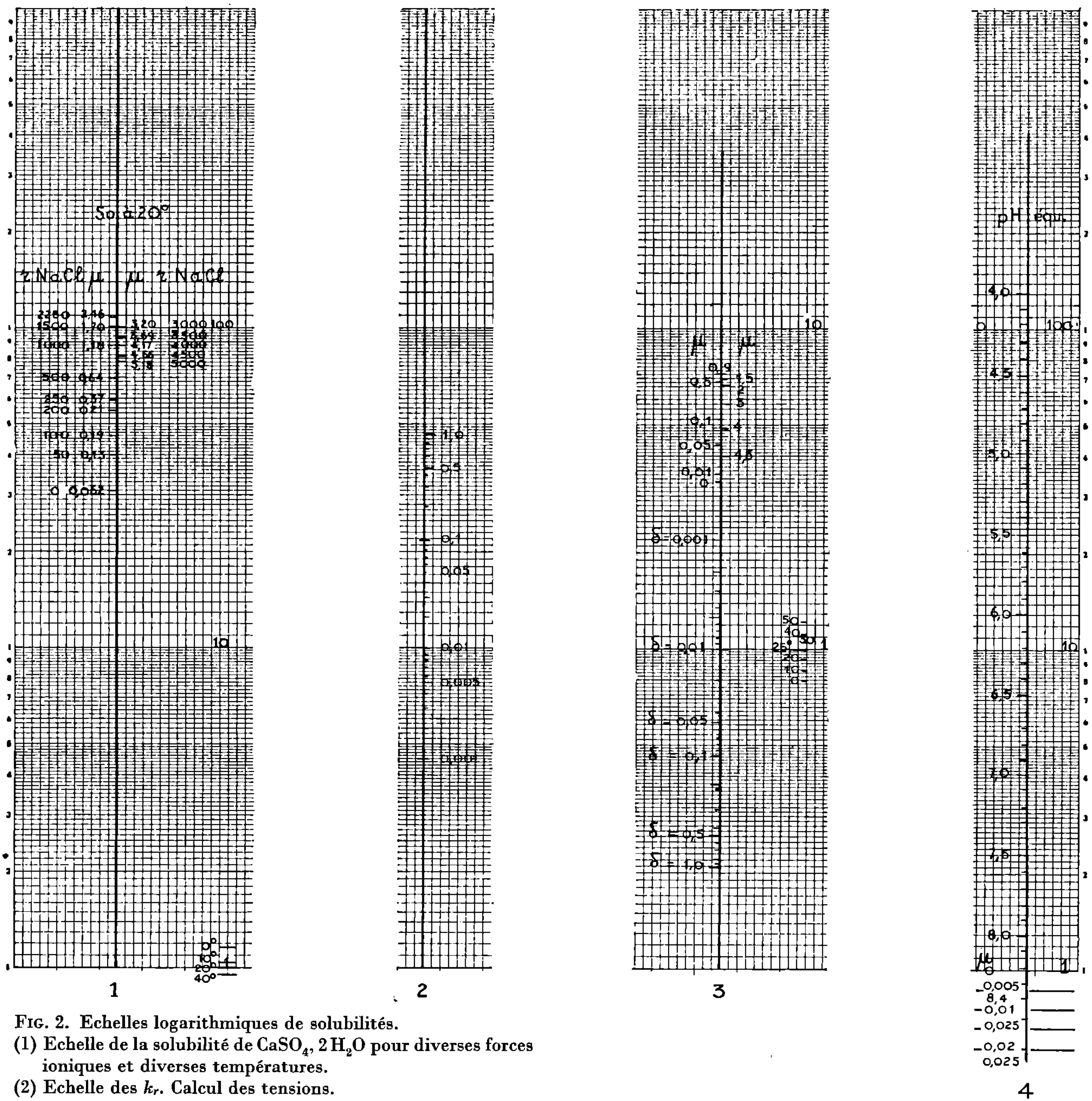

FIG. 2. Echelles logarithmiques de solubilités.

(1) Echelle de la solubilité de $CaSO_4$, $2H_2O$ pour diverses forces ioniques et diverses températures.

(2) Echelle des k_r. Calcul des tensions.

(3) Echelle des k_r, en fonction de la force ionique et de la température.

(4) Echelle des *p*H d'équilibre.

La concentration des eaux

Pour bien interpréter les analyses chimiques, il faut d'abord connaître les effets de la concentration sur la composition chimique des eaux [6, 11, 12, 13].

La concentration peut se faire par évaporation ou par dissolution. Dans la concentration par évaporation s'exerce une influence essentiellement climatérique. Les eaux sont d'autant plus chargées en sels qu'on va des régions tempérées ou des régions équatoriales vers les régions tropicales, désertiques.

En ce qui concerne la concentration par dissolution, les facteurs essentiels sont la température, la pression, la grandeur de la surface de contact, le volume de l'eau, le temps et le déficit de saturation de l'eau en tel ou tel sel.

Les principaux radicaux contenus dans les eaux sont les suivants: Ca, Mg, Na, Cl, SO_4, HCO_3, CO_3. Nous avons donc à examiner les solubilités et les produits de solubilité résultant de la combinaison de ces divers ions.

	Nombre de grammes par kg d'eau	Produit de solubilité
$CaCO_3$	0,013 à 18° C	0,48 × 10^{-8} à 25° C
$CaSO_4$	2,016 à 18° C	6,1 × 10^{-5} à 18° C
$MgCO_3$		1,4 × 10^{-4} à 16° C
$NaHCO_3$	96 à 20° C	
Na_2SO_4	193 à 20° C	
Na_2CO_3	213 à 20° C	
NaCl	263 à 20° C	
$MgSO_4$	355 à 20° C	
$MgCl_2$	546 à 20° C	
$CaCl_2$	745 à 20° C	

Les principaux sels qu'on rencontre dans les roches sont $CaCo_3$, $CaSO_4$, $MgCO_3$ et NaCl. Les autres ne se trouvent qu'à l'état de traces ou tout à fait exceptionnellement dans certains gisements. C'est la solubilité des premiers qui nous intéressera donc essentiellement.

Supposons que nous concentrions les sels contenus dans une eau, soit par évaporation, soit par de nouvelles dissolutions:

La concentration du sel le moins soluble $CaCO_3$ sera vite atteinte. D'ailleurs, on peut dire que, pour toutes les eaux, exception faite de celles qui se trouvent dans les terrains cristallins ou dans les terrains de sables ou de grès siliceux purs, les eaux sont déjà au voisinage de la saturation en $CaCO_3$.

La concentration augmentant, HCO_3 restera stationnaire et la teneur en autres ions s'accroîtra. Toutefois interviendra pendant ce temps le produit [Ca] [Co_3], qui aura tendance à diminuer HCO_3 par suite de l'accroissement en Ca apporté par $CaSO_4$.

Mais bientôt la saturation en $CaSO_4$ sera atteinte, SO_4 et Ca ne pourront plus alors s'accroître normalement. Il n'y aura qu'un accroissement dû à la force ionique de la solution. SO_4Ca est d'autant plus soluble que l'eau est plus chargée en NaCl. En effet la solubilité du $CaSO_4$ de 2,1 g/l à 20°, pour une concentration nulle de NaCl, croît jusqu'à 7,2 g/l pour une concentration de 146 g de NaCl, au-delà de laquelle la solubilité de $CaSO_4$ décroît.

Au-delà de la saturation en $CaSO_4$, seul le NaCl pourra continuer à se concentrer.

Si par exemple, au premier stade, on a:

$$rHCO_3 > rCl > rSO_4$$

ou

$$rCO_3 > rSO_4 > rCl$$

au deuxième stade, on aura:

$$rCl > rSO_4 > rHCO_3$$
$$rSO_4 > rCl > rHCO_3$$

au troisième stade, on aura toujours:

$$rCl > rSO_4 > rHCO_3$$

La limite entre le premier et le deuxième stade correspond à peu près à une concentration totale de 60 milliéquivalents. La limite entre le deuxième et le troisième stade est de 290 milliéquivalents. Mais, entre 180 et 290 milliéquivalents, on peut déjà avoir la séquence de ce troisième stade.

Il est aisé de voir que si on a, à l'origine, la séquence

$$rCa > rMg > rNa$$

on aura successivement:

$$rCa > rNa > rMg$$
$$rNa > rCa > rMg$$
$$rNa > rMg > rCa \text{ (séquence terminale)}$$

Si, pour une raison quelconque, une eau se concentre, que ce soit par évaporation, par enrichissement progressif, ou par dissolution, elle se transforme complètement et tend toujours vers une eau de séquence:

$$rCl > rSO_4 > rHCO_3$$
$$rNa > rMg > rCa$$

qui est celle de l'eau de mer.

On ne peut donc pas dire qu'une eau concentrée ayant la composition de l'eau de mer soit une ancienne eau "connée", puisque la concentration des eaux, de quelque origine qu'elles soient, aboutit à une composition voisine de celle de l'eau de mer.

Examen des valeurs

Pour interpréter les analyses, nous avons à examiner les valeurs absolues et les valeurs relatives des éléments.

HCO_3. La teneur en HCO_3 d'une eau dépend de la tension du CO_2 de l'atmosphère surmontant l'eau.

Dans les eaux en contact avec l'air atmosphérique, la tension δ est celle de l'air, soit 0,0003, ce qui est très peu et ne permet qu'une dissolution d'environ 50 mg/l de $CaCO_3$, c'est-à-dire d'environ 1 milliéquivalent de HCO_3.

Dans les eaux souterraines ordinaires, les teneurs en HCO_3 sont plus élevées et relativement constantes, car elles ne varient qu'entre 180 et 550 mg/l, dépassant rarement 660 mg/l. Les valeurs les plus courantes sont comprises entre 180 et 360 mg/l.

Que les eaux aient des teneurs élevées ou faibles en sels dissous, HCO_3 demeure toujours entre ces limites. Cette constance tout à fait remarquable de la teneur en HCO_3 est due à ce que HCO_3 est en équilibre avec la tension du CO_2 de l'atmosphère du sol agricole, qui oscille généralement entre 0,001 et 0,01. C'est en effet dans ce sol agricole que les eaux se chargent en CO_2, lors de leur infiltration.

Les teneurs plus faibles ou plus élevées doivent donc attirer l'attention.

Les teneurs plus faibles indiquent un contact avec l'air atmosphérique.

Les teneurs plus élevées sont produites par des phénomènes générateurs de CO_2: présence de matières organiques dans les terrains (pétrole, bitume, charbons, lignites, tourbes), réduction des sulfates. Elles peuvent aussi être dues à l'arrivée de CO_2 d'origine magmatique.

Comme nous venons de le dire, la teneur normale en HCO_3 des eaux souterraines est en relation avec la tension du CO_2 du sol agricole. Le climat doit donc avoir une influence. Le degré d'humidité du sol, la température sont en effet des facteurs essentiels de l'activité vitale dans le sol et en particulier de l'activité microbiologique, production de CO_2. C'est ainsi que la teneur en HCO_3 des eaux augmente graduellement du nord de la France jusqu'au centre de la Tunisie, où elle atteint son maximum, puis diminue vers le Sahara [11]; de la France au centre de la Tunisie, le facteur de contrôle de la production du CO_2 est la température; du centre de la Tunisie au Sahara, c'est l'humidité du sol.

Mais il faut faire intervenir divers correctifs, car la teneur en HCO_3 dépend également de la présence ou de l'absence de $CaCO_3$ dans les terrains. Si ceux-ci ne renferment pas de $CaCO_3$, à l'HCO_3 provenant de la dissolution du CO_2 gazeux ne s'ajoute pas le HCO_3 provenant de la dissolution du calcaire; dans ce cas, la concentration en HCO_3 est plus faible.

Dans tous les cas, pour avoir une vue plus exacte de la question, il faut déterminer les valeurs de Kr. En effet, si nous supposons qu'une dissolution élevée de $CaSO_4$ ou bien qu'un fort échange de bases amène des teneurs élevées en Ca, la concentration en HCO_3 devra nécessairement diminuer.

Cl. Il n'y a que très rarement limitation de Cl, car la saturation en NaCl n'est atteinte qu'exceptionnellement, sauf lorsque les eaux ont traversé des gîtes salifères ou subi une concentration par évaporation.

La solubilité du NaCl atteint 6120 milliéquivalents à 20°, et 6291 à 50°. Mais ce qu'il faut considérer, c'est $\sqrt{(r\mathrm{Na})\,(r\mathrm{Cl})}$, sur la verticale placée à mi-chemin entre *r*Na et *r*Cl.

Au voisinage de la saturation, un échange de Na de l'eau contre Ca ou Mg, par exemple, pourra augmenter la teneur en Cl. Nous l'avons fréquemment observé. Inversement, on pourrait concevoir qu'un apport de Na à l'eau par échange de bases fasse diminuer Cl. Mais les eaux présentant ces concentrations de *r*Na, supérieures à 6120–6291 milliéquivalents, sont tout à fait exceptionnelles.

SO_4. La concentration de l'eau par évaporation ou par dissolution augmente la teneur en SO_4. Mais cette augmentation se fait de moins en moins rapidement au fur et à mesure qu'on approche de la saturation. Seule la solubilité du $CaSO_4$ est la cause de la limitation de la concentration en SO_4. En effet, les autres sulfates sont beaucoup plus solubles. Ils n'entrent pas en jeu. Il faut donc considérer le produit (rSO_4) (*r*Ca), sans oublier que ce produit augmente avec la force ionique de la solution, en particulier avec la teneur en NaCl, jusqu'à un maximum au-delà duquel il diminue (cf. tableau 1). S_0 maximum est de 107 milliéquivalents.

Si une eau est déjà saturée en $CaSO_4$, un apport de Ca par échange de bases aura pour effet de diminuer SO_4. Il y aura précipitation de $CaSO_4$; rSO_4 pourra même présenter des valeurs très faibles qu'il faudra prendre garde de ne pas attribuer à une réduction des sulfates; dans tous les cas, on aura $rSO_4 < r\mathrm{Ca}$.

Une diminution de la teneur en Ca par un échange de bases ou par précipitation de $CaCO_3$ permettra une nouvelle dissolution de SO_4. Dans le cas d'un échange de bases négatif, rSO_4 pourrait donc dépasser de beaucoup *r*Ca. Mais, comme ces nouvelles dissolutions se feraient surtout à partir du $CaSO_4$ des terrains, il y a peu de chances pour que rSO_4 devienne plus élevé que S_0 (cela ne se produirait que par dissolution de $MgSO_4$ ou d'un autre sulfate). Et c'est effectivement ce que l'on constate: rSO_4 ne dépasse guère 140 milliéquivalents, S_0 maximum étant de 107 milliéquivalents.

Rapport $rSO_4/r\mathrm{Cl}$. A des concentrations faibles, c'est-à-dire tant que [Ca] [SO_4] n'est pas voisin du produit de solubilité, le rapport $rSO_4/r\mathrm{Cl}$ est en général caractéristique d'une nappe d'eau souterraine, en raison de son alimentation et de la nature de ses terrains. Mais, lorsque les eaux continuent à attaquer ou dissoudre les éléments des roches, la concentration en Cl a tendance à augmenter plus rapidement que celle en SO_4, car la vitesse de dissolution des chlorures est plus grande que celle des sulfates. En effet, le déficit de saturation des premiers est supérieur à celui des seconds. Et, plus on approche du point de saturation du $CaSO_4$, plus cette tendance s'accentue.

Ainsi, plus l'eau se concentre, plus le rapport $rSO_4/r\mathrm{Cl}$ diminue. On comprend que si les terrains aquifères sont très riches en sulfates, pour les mêmes raisons, lors d'une concentration par dissolution, le rapport $rSO_4/r\mathrm{Cl}$ augmente d'abord, pour ne diminuer qu'au-delà d'un certain seuil, ce que nous avons observé pour la nappe du Quaternaire du Mornag en Tunisie.

La concentration par évaporation amènera naturellement une diminution graduelle du rapport $rSO_4/r\mathrm{Cl}$.

N'oublions pas que, là encore, pour interpréter correctement les phénomènes, il faut tenir compte du produit (rSO_4) (*r*Ca).

Ca. Le calcium est apporté par la dissolution du $CaCO_3$ et du $CaSO_4$.

Si la mise en solution du Ca se limitait à cela, les eaux ne renfermeraient que de faibles quantités de calcium.

Or on constate que de très nombreuses eaux renferment des quantités de Ca très importantes, pouvant aller jusqu'à 1200 milliéquivalents. C'est que du Ca est alors apporté par des échanges de bases.

Pour étudier la limitation du Ca, on tiendra compte des produits (rSO_4) (*r*Ca) et ($rHCO_3$) (*r*Ca).

Mg. Le magnésium présente lui aussi des valeurs très variables, mais qui sont loin d'atteindre celles du calcium, malgré la plus grande solubilité de certains de ces sels. Il ne semble pas que la teneur en Mg dépasse 530 milliéquivalents. C'est que la teneur en Mg des terrains est relativement faible. Les fortes teneurs en Mg proviennent surtout des terrains gypso-salifères, et en particulier des échanges de bases.

Rapport rMg/rCa. Ce rapport est caractéristique, dans une nappe située dans un même terrain, tant que des phénomènes secondaires n'interviennent pas.

Lorsque la concentration générale de l'eau augmente, Ca lié à $CaCO_3$ ne peut s'accroître, car HCO_3 est fixe. Au contraire, Mg peut provenir de la dissolution du gypse ou des terrains salifères qui en contiennent toujours plus ou moins.

De plus, au voisinage de la saturation en $CaSO_4$, la dissolution de $CaSO_4$ devient de moins en moins rapide par rapport à celle de $MgSO_4$ et de $MgCl_2$. Aussi observe-t-on alors une augmentation du rapport rMg/rCa.

D'autres causes modifient ce rapport; tels sont les échanges de bases négatifs qui l'accroissent (nappe de l'albien du bassin de Paris, nappe de l'éocène de l'Oued el Kebir en Tunisie, eaux de gisements de pétrole, etc.). En effet, les ions Ca et Mg ne sont pas aussi facilement échangeables avec les ions Na. Les ions Ca sont beaucoup plus énergiquement fixés que les ions Mg. Inversement, un échange de bases positif diminue le rapport rMg/rCa.

Rapport $\frac{rNa + rK}{rCl}$. Le rapport entre Na + K et Cl est de première importance.

Toute différence $rNa + rK — rCl$ des eaux indiquerait *a priori* qu'elles ont dissous, outre du NaCl, du sulfate de soude ou du carbonate de soude, si $rCl < rNa + rK$, ou encore du chlorure de calcium ou du chlorure de magnésium si $rCl > rNa + rK$. Cela nous amène à rechercher les causes de cette différence.

Tout d'abord, il y a une acquisition de la différence $rNa\ rK — rCl$ par dissolution à l'origine de l'évolution chimique. Elle est peu fréquente car ces substances sont assez rares dans les assises géologiques.

Il est vrai que, dans les régions désertiques en particulier, il y a superficiellement accumulation de Na_2SO_4 et de Na_2CO_3, ce qui conduira à l'inégalité $rCl < rNa$.

Il est vrai aussi que, déjà dans l'eau de mer, on a $rCl > rNa$ et que, si les sédiments ont adsorbé, lors de leur précipitation, les cations Na, Mg, Ca de l'eau de mer, il peut y avoir, par contact d'eau nouvelle, restitution de la même inégalité.

Enfin il y a une acquisition à l'origine de l'évolution chimique de cette différence par attaque des roches cristallines. Cette attaque donnera obligatoirement l'inégalité $rNa + rK > rCl$, car les teneurs en Cl de ces roches sont considérablement plus faibles que celles des alcalins.

Ensuite il y a une modification des rapports existant entre les alcalins et le chlore, à la suite d'échanges de bases entre l'eau et le terrain aquifère.

Il peut y avoir échange d'alcalins de l'eau contre des calco-alcalins des terrains. Si primitivement il y avait dans l'eau autant de $rNa + rK$ que de rCl, le rapport $\frac{rCl — rNa — rK}{rCl}$ serait le même que le rapport existant entre les ions $rNa + rK$ de l'eau échangés et les ions $rNa + rK = rCl$ existant primitivement dans l'eau, cela dans le cas de $rCl — rNa — rK > 0$.

Le rapport $\frac{rCl — rNa — rK}{rSO_4 + rHCO_3}$ serait le même que le rapport existant entre les ions rCa et rMg de l'eau échangés contre des ions rNa et rK des terrains et le $rCa + rMg = rSO_4 + rHCO_3$ existant primitivement dans l'eau. Nous avions appelé ces indices "indices d'échange de bases" [7].

Mais il est souvent très difficile de faire le partage entre les acquisitions primitives et les échanges de bases ultérieurs. Aussi avons-nous plus récemment appelé cet indice "indice de déséquilibre chlore-alcalin" [18].

Si l'on fait une statistique de cet indice, en fonction de la teneur en Cl, on constate [17] que l'indice pour les faibles concentrations de Cl peut être soit positif, soit négatif. Au-delà d'une certaine concentration, il est toujours positif. La limite du Cl au-dessus de laquelle l'indice est toujours positif ne dépasse pas 500 milliéquivalents. Je n'ai trouvé que quatre exceptions sur 646 eaux. Il y en a certainement quelques autres. Mais, comme on le voit, elles doivent être très rares.

Il est tout à fait remarquable de constater que cette limite de 500 rCl et, par conséquent, de $rNa + rK$, au-dessus de laquelle les échanges de bases négatifs cessent, est très voisine de la concentration en Na + K de l'eau de mer, en moyenne de 475 milliéquivalents, variant entre 448 et 505.

Il ne doit pas s'agir d'une simple coïncidence. En effet, pendant et après leur précipitation, les vases marines ont dû s'établir en équilibre d'échange de bases avec l'eau de mer et les eaux d'imbibition des vases marines, dont la teneur en Cl et Na ne diffère pas beaucoup de celle de l'eau de mer.

Par conséquent, lorsque des eaux souterraines à concentration en Na + K supérieure à celle de l'eau de mer pénètrent dans d'anciens sédiments qui avaient été en équilibre de bases avec l'eau de mer, un déséquilibre se produit. L'eau souterraine, chargée d'une plus grande quantité d'alcalins que l'eau de mer, ne peut que céder du Na + K contre du Ca + Mg de la roche. Si l'indice de déséquilibre était négatif, il deviendra positif. Au-dessus de 500 rCl environ, l'indice tendra donc toujours à être positif.

Les exceptions peuvent s'expliquer dans le cas de sédiments se précipitant dans des eaux lagunaires sursalées; effectivement, elles correspondent bien à des eaux situées dans des roches de faciès lagunaire.

Eaux superficielles comparées aux eaux souterraines

Nous voudrions terminer par une comparaison entre les eaux superficielles et les eaux souterraines.

Si les eaux superficielles n'ont que des concentrations relativement faibles, comme c'est le cas le plus fréquent dans les régions tempérées, l'une des caractéristiques les plus importantes permettant de les différencier des eaux souterraines est la faible valeur de Kr. La raison en est à chercher dans le fait qu'elles sont en contact avec l'air atmosphérique. HCO_3 et CO_3 de l'eau se mettent alors en équilibre avec la tension extrêmement faible du CO_2 de l'air atmosphérique, 0,0003.

Si les eaux superficielles sont concentrées, comme dans les régions arides, pour la même raison Kr est faible. Cependant il faut tenir compte du fait que la force ionique de la solution peut l'augmenter plus ou moins.

De plus, comme toutes ces eaux superficielles concentrées le sont par évaporation, que ce soit l'eau de mer, l'eau des lagunes sursalées, l'eau de certains lacs intérieurs, d'autres caractéristiques viennent s'ajouter, qui peuvent, elles aussi, s'expliquer assez facilement.

En particulier le rapport $r\text{Mg}/r\text{Ca}$ est toujours très élevé, bien supérieur à 1. Cela est dû à la précipitation du $CaCO_3$ d'abord, puis du $CaSO_4$ de l'eau, alors que Mg ne cesse de s'accroître. De même le rapport $r\text{Mg}/r\text{Na}$ prend souvent des valeurs élevées inhabituelles, lorsque NaCl commence à se précipiter.

Enfin, comme Ca se précipite abondamment, par compensation rSO_4 peut augmenter et atteindre des valeurs de 1400 alors que, dans les eaux souterraines, rSO_4 ne dépasse pas 420.

Tandis que dans les eaux souterraines au-dessus de $r\text{Cl} = 500$ l'indice de déséquilibre chlore-alcalin est toujours positif, ici il peut être également négatif.

SUMMARY

Interpretation of chemical analyses of saline waters
(H. Schoeller)

Ground-water and surface-water comprise a great range of types, varying extensively in chemical composition according to the climatic, geological and hydrological influences operative.

In order to arrive at the reasons for the different water profiles which result from these influences, comparison of their chemical analyses is essential and for this purpose semi-logarithmic graphs present great advantages.

The method is to mark off the elements in the order Ca, Mg, Na + K, SO_4, Cl, HCO_3 on the abscissa, and to set out on the ordinate the logarithms of the milliequivalents; values must not be expressed as percentages.

In addition, the graphs permit direct calculation of the relative proportions of the various elements and the determination of the solubility products and saturation levels. They also enable the absolute values to be used; in fact these cannot be disregarded, particularly the solubility products since it is their interplay which exhibits the evolution of the water's chemical profile towards the terminal state expressed in the sequence $r\text{Cl}–rSO_4–HCO_3–r\text{Na}–r\text{Mg}–r\text{Ca}$.

The absolute values most important to consider are HCO_3, Cl and SO_4, but the products $[HCO_3]\,[\text{Ca}]$, $[\text{Cl}]$, $[\text{Na}]$ and $[SO_4]\,[\text{Ca}]$ must also be taken into account.

The principal ratios are $rSO_4/r\text{Cl}$, $r\text{Mg}/r\text{Ca}$ and $\frac{r\text{Na} + r\text{K}}{r\text{Cl}}$.

DISCUSSION

A. Hafiz. I should like to know if there is any correlation between the concentration of ground-water and the nature of the agricultural soil.

H. Schoeller. Il y a une relation entre la composition chimique des eaux souterraines et la nature pédologique du sol pour les podzols et les sols bruns, par exemple. En revanche, dans les régions arides, la concentration des eaux voile toutes relations.

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SOME CHEMICAL TYPES OF GROUND-WATER FROM SYRIA

by

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COMPILATION OF DATA

The data on which this paper is based are the result of six years of investigation in Syria, from 1952 to 1958. The investigations were carried out as part of a programme for the survey and development of the ground-water resources of Syria.

Water samples

The 70 analyses were selected from 781 made on water samples collected from springs, *fogarras,* wells and bore-holes scattered all over Syria. The selection was made so as to get a representative sample for the country west of the Euphrates river; but the method adopted was to take what appeared to be a typical water, rather than to undertake a detailed study of all the analyses made on waters from each area. When such a full investigation has been made, it may modify, but cannot substantially alter, the conclusions reached in this paper.

The analyses have been carried out at Riverside, California (reported by Wilcox, Table 61/52); at the Stazione Chimico-Agraria Sperimentale, Rome; at the Central Government Laboratory, Amman (Dr. J. Habayeb); and at the Laboratory of the Ministry of Agriculture, Damascus (Dr. Amin Sharif). In general, the results from one laboratory have agreed fairly well with those from another. Within each laboratory, analyses made on the same water sampled at different times (as during a test-pumping of a bore-hole, when three samples are normally collected) have shown excellent agreement. It will be noted that only at Riverside have the total anions and cations been determined separately; elsewhere the sums have been assumed equal and the missing cation or anion determined from this assumption; accordingly, there is no internal check on the accuracy of such analyses.

Some trace elements, such as boron, fluorine, phosphorus and iron, have been determined in some laboratories in some samples; these results have been excluded from this paper. So also have data on colloids in solution-suspension, since they have not been determined on all samples.

Lithology and geology of the aquifers

In this investigation, major emphasis has been placed on the lithology of the aquifers; a limestone aquifer—be it Jurassic, Middle Cretaceous or Nummulitic—tends to impart the same general chemical composition to the ground-water flowing through it. But this is only a tendency, and different limestone aquifers, by their different structural histories, by the different topography which they produce and by the lithologically different beds which may occur associated with them, may produce ground-waters whose chemical characteristics are specific to the limestones of each geological age. Nevertheless, this general investigation shows that in Syria limestone aquifers have certain common characteristics which over-ride differences attributable to the specific characteristics of the limestones of different age occurring in that region.

Table 1 shows that in choosing typical waters from Syria west of the Euphrates, more have been selected from limestone than from any other aquifers. This is due to the fact that over much of Syria west of the Euphrates, limestones of varying ages (Jurassic, Middle Cretaceous,

TABLE 1. The 70 samples of water from Syria west of the Euphrates river, classified according to the aquifers from which they were obtained

No. of samples	Lithology of aquifer
28	Limestone
12	Altered, weathered marl
8	Plateau basalt
8	Fars Formation (Lagoonal)
5	Lacustrine marls and other Quaternary sediments
5	Chert-Flint of Rmah
4	Conglomerates and other terrestrial deposits

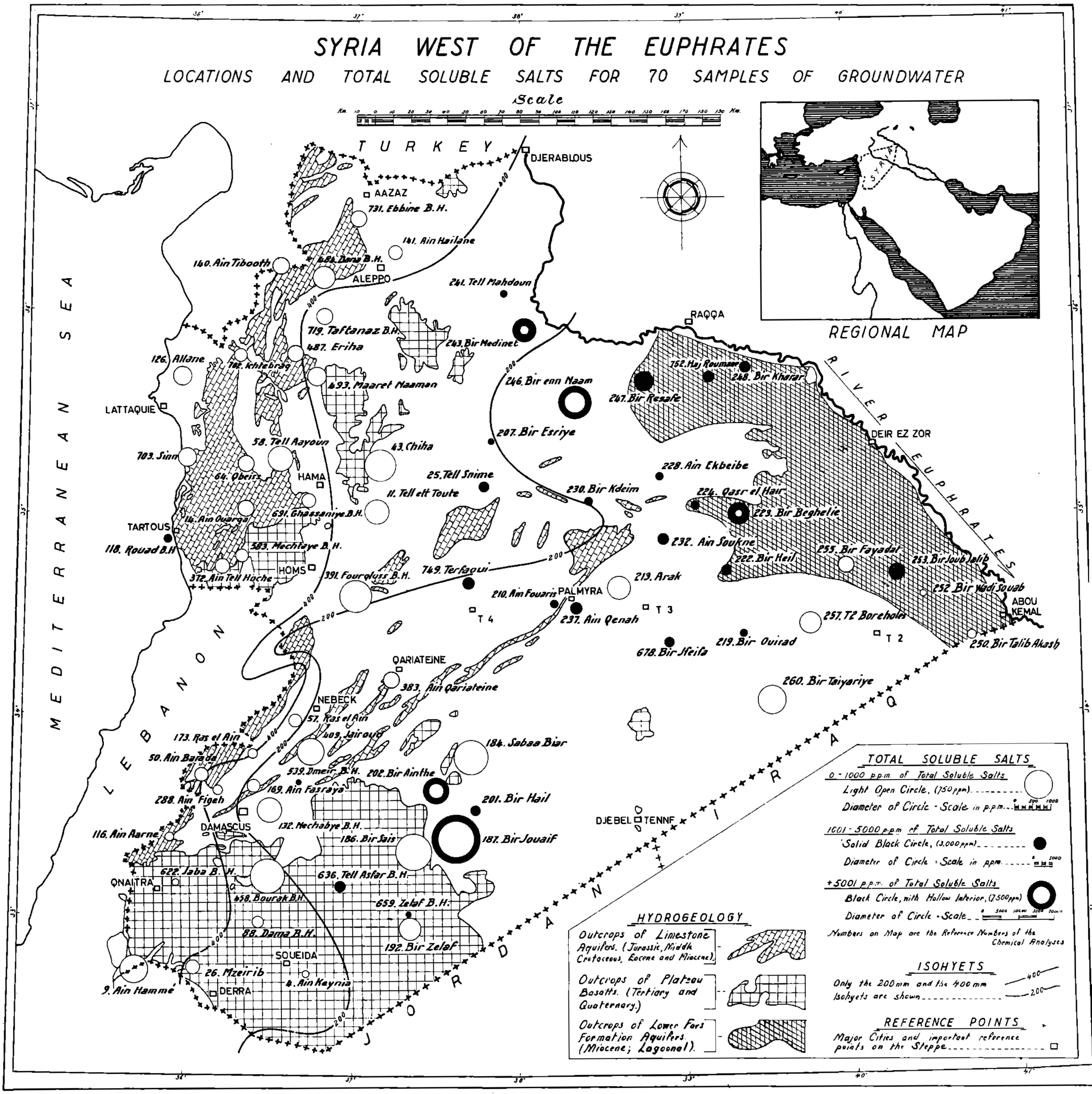

Fig. 1. Map of Syria west of the Euphrates river, showing the locations from which the 70 samples of ground-water were collected and indicating the total soluble salt content by the size and shading of the circles. The outcrops of the Limestone, Basalt and Fars Formation aquifers are also shown.

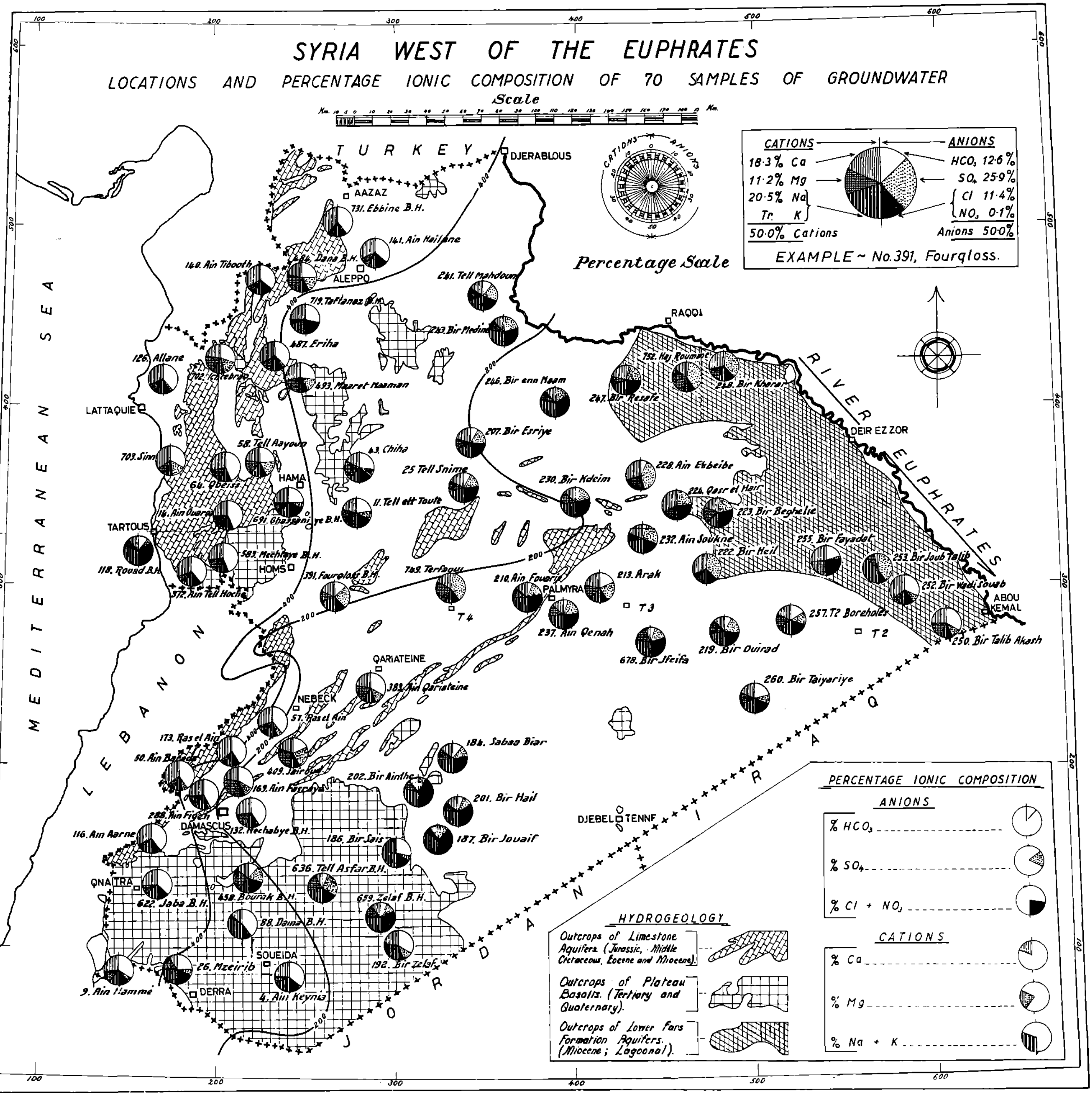

FIG. 2. Map of Syria west of the Euphrates river, showing the locations from which the 70 samples of ground-water were collected and indicating the percentage ionic composition of each sample by the shading on the circles. The outcrops of the Limestone, Basalt and Fars Formation aquifers are also shown.

Nummulitic and Miocene) are the main aquifers. Other clear-cut and important aquifers are the Tertiary and Quaternary plateau basalts and the Lagoonal, usually gypsiferous, Lower Fars Formation. These three aquifers have been shown on figs. 1 and 2. The areas on the map left without cross-hatching are mainly chalk and marl, though in places there are extensive Neogene and Quaternary lacustrine and terrestrial deposits, which are aquifers; in the extreme north-west there are serpentines and gabbroes not considered in this paper. The altered, weathered chalk and marl are valuable aquifers, yielding water from *fogarras* and wells, but seldom giving rise to natural springs. These aquifers are superficial, however, and of no importance in drilling deep bore-holes. The Rmah Chert is of Campanian age and is an important local aquifer.

Precipitation and evapotranspiration

The 400 mm. and 200 mm. isohyets shown on figs. 1 and 2, and the rainfall data on which fig. 5 is based, were obtained from the "Middle East rainfall map", published by Fish and Dubertret in 1945. The amount of precipitation is found to be very much less important than the lithology of the aquifers in determining the chemical composition of the ground-water.

It will be seen (see Table 3 for details) that of the 70 samples, 33 come from the regions of less than 200 mm. average rainfall. Of the 37 from areas of more than 200 mm. average precipitation, 22 are from those having an average precipitation of over 400 mm.

Temperatures of ground-water

It is regretted that insufficient observations of the temperatures of ground-water have been made to determine monthly changes or to relate temperatures to chemical composition or to the origin of the Syrian ground-water. In a few limited areas, where sufficient observations of temperature have been made, useful deductions have been made, as for the Middle Cretaceous limestone aquifers west of Hama, of which no. 691 is an example [2].[1]

Previous investigations of the area

Frolow investigated the chemical composition of ground-water in Aleppo, Palmyra, Damascus and around Hermon; a summary of his findings are given on pages 87–90 of *L'eau des continents et ses mécanismes.* He was mainly concerned with monthly variations in the total soluble salts in the water. His findings were not related to the hydrogeology of the regions. Paver [21] gave a small map showing the chemical composition of ground-water in Syria; this map was revised and formed fig. 2 of "Ground-water in Syria" by Burdon, Mazloum and Safadi [5].

More detailed investigations have now shown that it is well-nigh impossible to show generalized composition without unduly simplifying the chemical details and without ignoring the fact that certain aquifers are restricted in area and cannot be considered to cover large regions of the country. Accordingly, different principles have been followed in fig. 1 of this paper to show the chemical composition of the ground-water in Syria.

CHEMICAL TYPES OF GROUND-WATER FOUND IN SYRIA

The chemical composition of the 70 samples is shown in fig. 3. This modified Durov diagram is very useful for comparing the chemical characteristics of a large number of samples. Potassium is combined with sodium, and nitrate with chloride. In addition, the type of aquifer (limestone, basalt, etc.) from which each water was derived is indicated, as is the general relationship between percentage anion composition and total soluble salts. Table 2 classifies the number and percentage of the 70 samples, which fall into different groups according to the way in which the cations and anions are combined in each water.

TABLE 2. Combinations of cations and anions in 70 samples of ground-water from Syria west of the Euphrates river (expressed as numbers and percentages of the total)

Dominant (+ 25%)	HCO_3	SO_4	Cl	Mixed	Total
	%	%	%	%	%
Ca	22 (31.4)	3 (4.3)	2 (2.9)	0 (0.0)	27 (38.6)
Mg	0 (0.0)	2 (2.8)	0 (0.0)	3 (4.3)	5 (7.1)
Na	3 (4.3)	1 (1.4)	10 (14.3)	0 (0.0)	14 (20.0)
Mixed	9 (12.9)	3 (4.3)	4 (5.7)	8 (11.4)	24 (34.3)
Total	34 (48.6)	9 (12.8)	16 (22.9)	11 (15.7)	70 (100.0)

The anions, HCO_3, SO_4 and Cl, are the most mobile constituents of ground-water and form the most satisfactory basis for classification, especially when investigating the genesis and metasomatism of ground-water [3]. The cations, Ca, Mg and Na + K, are of medium mobility and are subsidiary to the anions in classifying the waters. Hence waters are first classified according to the dominant anion; this dominant anion will account for more than 50 per cent of all the anions expressed as percentage milligram equivalents per litre. These primary groups are subdivided according to the percentage of associated cations; here again, the dominant cation will amount to more than 50 per cent of all the cations.

Accordingly, four major groups of ground-water emerge:

1. *Bicarbonate group,* with either Ca, Mg or Na + K as the dominant cation, and with SO_4 and Cl in smaller amounts than the HCO_3.
2. *Sulphate group,* with either Ca, Mg or Na + K as the dominant cation, and with HCO_3 and Cl in smaller amounts than the SO_4.

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[1] The figures in brackets refer to the bibliography on page 89.

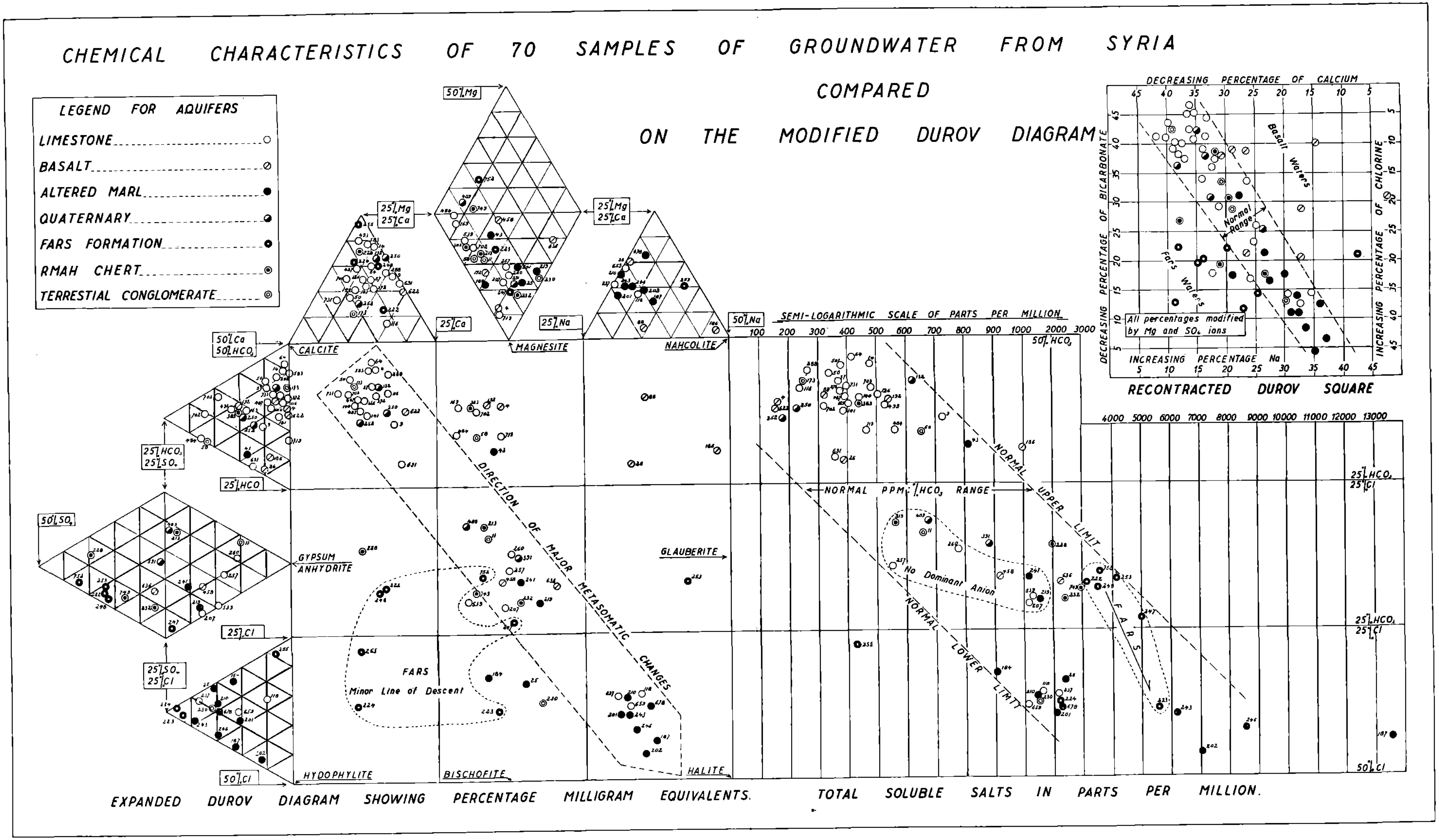

FIG. 3. Chemical characteristics of 70 samples of ground-water from Syria, compared on the expanded Durov diagram. The diagram shows the percentage milligram equivalents per litre for the anions HCO_3, SO_4 and $Cl+NO_3$, and the cations Ca, Mg and $Na+K$ for each sample, plotted on expanded equilateral triangles constructed on two sides of a square into which the positions of the anion and cation points for each water have been projected. The points so obtained are also projected to the right, where plotting on a semi-logarithmic scale shows the relationship between total soluble salts and varying percentages of the HCO_3 and the $Cl+HNO_3$ anions.

Accordingly, each sample is plotted four times on the main diagram, and the shading on the circles indicates the aquifer from which the water was obtained. In addition, the re-closed square is shown at the right, to emphasize relationships between waters separated for clear identification on the main diagram. This method of displaying the chemical characteristics of a large number of waters is based on the Durov diagram [11], as reported by Chilingar [6] and modified by Burdon [3].

3. *Chloride group,* with either Ca, Mg or Na + K as the dominant cation, and with HCO_3 and SO_4 in smaller amounts than the Cl.
4. *Mixed group,* with no one anion exceeding 50 per cent of the total anions.

Fig. 3 is a modification of Durov's diagram [11, p. 90; 7, p. 194], designed so as to show the relationships between these different groups of water and above all to show the way in which metasomatic processes allow water to change from one group to another. The alterations made by Burdon [3, fig. 1] are designed to open up the triangles so as to sharply separate waters with anions or cations forming more than 25 per cent of the total milligram equivalents per litre from waters with no anion or cation greater than the sum of the percentages of the others. This opening-up of the triangles tends to remove from each other waters which are chemically close when plotted on the resulting square. Accordingly, waters are shown plotted both on the open square and on a re-closed square.

Total soluble salts are also plotted; the scale is semi-logarithmic. It can be seen that the total soluble salts are plotted against variations in the relative percentages of bicarbonate and chloride.

Fig. 3 is also an illustration of the lines of chemical metasomatism or descent for ground-water. Commencing as a bicarbonate water, ground-water has a major line of descent to chloride water and a minor line of descent to sulphate water. Normally, the two lines are intermingled to form a mixed line of descent; seldom does the water follow the major line of descent without taking into solution some sulphate, and seldom do carbonate-sulphate waters contain no chloride. But although the mixed line of descent is general, still as total soluble salts increase, so does chloride tend to become more and more the dominant anion. Fig. 4 sets out in schematic form these lines of descent of metasomatism for ground-water.

Bicarbonate waters of Syria

Of the 70 samples analysed, 34 contain more than 25 per cent of the bicarbonate anions (Table 2). In these 34 samples, associated cations show more than 25 per cent Ca in 22 cases, more than 25 per cent Na in 3 cases; no cation exceeds 25 per cent in the remaining 9 cases. It will be noted that there is no bicarbonate water with dominant Mg. It will also be noted (fig. 3) that no water containing more than 25 per cent of bicarbonate has more than 1,000 ppm. of total soluble salts, and that only three (nos. 186, 43 and 9) exceed 700 ppm. The primary nature of the bicarbonate, and especially of the bicarbonate-calcium, waters is clear.

The geographical distribution of the bicarbonate waters is shown in figs. 1 and 2. The thin circumferenced circles indicate less than 1,000 ppm. of total soluble salts, and since only 9 of the 43 samples with less than 1,000 ppm. of total soluble salts are not + 25 per cent bicarbonate, the light circles refer mostly to waters with dominant bicarbonate. It will be noted (Table 3) that of the 34 samples with dominant bicarbonate, 28 occur within the region with more than 200 mm. rainfall; and of these 28, 21 occur where the rainfall is in excess of 400 mm. Again, the distribution of the bicarbonate waters indicates their primary nature. They occur where rainfall is heaviest, where infiltration is high and where there is such abundant ground-water in the nappes that the chemical nature of the aquifers is of lesser importance in determining the composition of the water.

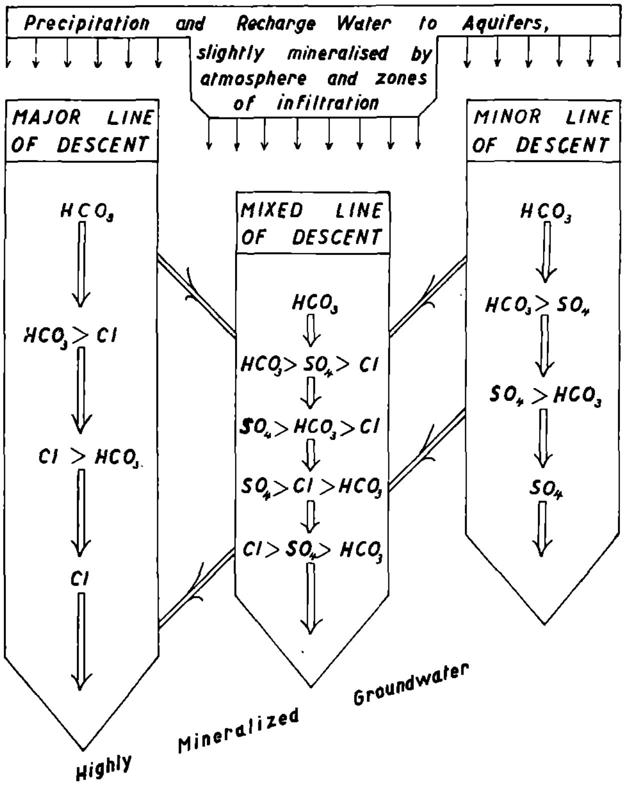

FIG. 4. The lines of chemical descent for ground-water. A simple diagram, showing the major and minor lines of metasomatic changes in the chemical composition of ground-water, as well as the mixed line of descent. Based on Burdon's paper "Metasomatism of ground-water at depth", read at Cairo, January 1958.

The six bicarbonate waters (nos. 132, 186, 192, 250, 252 and 383) from regions with less than 200 mm. of rainfall deserve special attention. No. 132 is from the Nechabye bore-hole in the Damascus Ghouta; the ground-water originates in the high rainfall hills to the north-west. Nos. 186 (Djebel Sais) and 192 (Zelaf) are from basaltic aquifers, which characteristically do not yield sulphur or chlorine to replace the bicarbonate; it will be noticed that with 999 ppm. and 538 ppm. of total soluble salts, respectively, these waters are much more mineralized than is usual for basaltic waters.

Nos. 250 (Bir Talib Akash; 224 ppm.) and 252 (Bir Wadi Souab; 175 ppm.) pose an unusual problem. They occur in major wadis, draining large areas to the south and south-west; Wadi Souab extends for some 300 kilometres from the well. It is clear that the water originates from infiltration along the wadi bed and is found either in the alluvium infilling the wadi or in solid rock aquifers recharged through and from the alluvium. The samples were collected in May 1955, and so some time after the winter rains. It seems clear that these major lines of drainage, incised during the Pluvial Periods of the Quaternary, have managed to remain unblocked, so that evaporation in closed basins, with consequent concentration of soluble salts, has not occurred. It is also possible that the salts have been washed from the region, probably during the Pluvials.

Sample no. 383 is from Ras el Ain Qariateine, and arises from the Rmah Chert aquifer. Its composition and low total soluble salts (436 ppm.) may be due to local infiltration into Djebel Mzeible to the south-west, and so to a short passage through the aquifers, and also to the fact the water has not come into contact with aquifers containing soluble salts.

Finally, attention must be drawn to 13 samples containing less than 5 per cent of the bicarbonate anion. Of these, none contains less than 2,000 ppm. of total soluble salts, and 7 occur in aquifers of the Fars Formation, where abundant chlorides and sulphates are available to dominate the bicarbonate. It must be realized that if total soluble salts increase by solution of sulphate and chloride minerals, then the percentage of bicarbonate will decrease, even if there is no precipitation of carbonates and escape of carbon dioxide [4]. Four samples (nos. 187, 202, 243 and 246) occur in altered, weathered marl. Of these four, two occur in regions of closed drainage at Ej Jouaif and Bir Aithe; with total soluble salts of 13,516 ppm. and 7,013, they illustrate the principle that when total soluble salts are high, bicarbonate is of minor or no importance. The other two occur at Bir Medinet (6,183 ppm.) and Bir Enn Naam (8,528 ppm.), and may be due to a number of causes: poor drainage, cover by Fars Formation and salinization in the past, or the presence of primary salts in the rocks, such as gave rise to the salt lake of Jabboul to the west. The remaining two waters with abnormally low bicarbonate content (nos. 232 and 749) come from the Rmah Chert aquifer. The relationships between aquifers and the composition of the waters they contained are discussed more fully in the section "Factors controlling the chemical composition of the ground-water", pages 82–87 of this paper.

Sulphate waters of Syria

Of the 70 samples considered here, only 9 contain more than 25 per cent the sulphate anion (Table 2). In these 9 samples, associated cations show more than 25 per cent Ca in three cases (nos. 222, 228 and 248), more than 25 per cent Mg in two cases (nos. 749 and 752) and more than 25 per cent Na in one case (no. 253). In eight of these nine cases, total soluble salts exceed 1,000 ppm.; the exception is no. 391 from Fourqloss. But in none of them does total soluble salts exceed 3,600 ppm. These facts are set out in fig. 3.

The geographical distribution of waters with dominant sulphate may be seen on figs. 1 and 2. In eight cases they are found in regions where the precipitation is less than 200 mm. per annum; the exception is again no. 391 from Fourqloss, where rainfall just exceeds 200 mm. per annum. The other eight are in circles with dark borders on the map. They tend to lie in the area between Palmyra and the Euphrates, where the Fars Formation outcrops; but Wadi Terfaoui (no. 749) and Tell Asfar (no. 636) lie outside this general region.

It will be seen from fig. 3 that four of the nine high-sulphate waters are from Fars Formation aquifers; this is a clear case of chemical control by the aquifer and will be discussed more fully in the section on "Fars Formation aquifer" on page 85. So also will the fact that of the remaining five high-sulphate waters, three come from Rmah Chert aquifers; the two others come from basaltic and lacustrine marl (Fourqloss) aquifers.

The waters with low sulphate content also deserve notice; 21 out of the 70 samples have less than 5 per cent sulphate. As may be seen from fig. 3, 20 of these are taken from waters in which the bicarbonate anion exceeds 25 per cent; only one (no. 255) comes from water with a high Cl content. It will also be seen that the low sulphate waters occur almost entirely (18 out of 20) in limestone and basalt aquifers. No. 255 is from Bir Fayadat, where water from Wadi Miah with a high bicarbonate percentage and low total soluble salts appears to mingle with water from the Fars Formation with low bicarbonate and high total soluble salts. It was noticeable that the spoil-heap from Bir Fayadat showed no gypsum.

Finally, it should be noticed that waters with high SO_4 content are rather rarer in Syria than might be expected. Even in the Fars Formation, with abundant gypsum and anhydrite, and probably some epsomite ($MgSO_4 \cdot 7H_2O$) and glauberite ($Na_2SO_4 \cdot 10H_2O$), as well as other rarer sulphate precipitate salts, the sulphate content of the waters is low. Again, in the basins of closed drainage, high sulphate contents would be expected; this sulphur would originate from the oxidation of pyrite-marcasite which is common in the chalk-marls of the Upper Cretaceous and Lower Tertiary in Syria. It would seem that the absence of a high percentage of sulphates in these waters is due to the fact that their total soluble salt content is high, and once total soluble salts exceed 3,500 ppm., chloride becomes dominant over sulphate. This is due to the higher solubility of chlorides as compared with sulphates. Thus NaCl is 1.7 times more soluble than Na_2SO_4, while $CaCl_3$ is over 200 times more soluble than $CaSO_4$. (See also Table 8 of "Metasomatism of Ground-water at Depth" [3].)

Chloride waters of Syria

Of the 70 samples considered here, 16 contain more than 25 per cent of the chloride anion (Table 2). In these 16 samples, associated cations show more than 25 per cent Ca in 2 cases and more than 25 per cent Na in 10 cases; in the remaining 4 cases there is no dominant cation, so that in none of the chloride waters does the Mg ion exceed 25 per cent. In only two cases (nos. 184 and 255) do total soluble salts fall below 1,000 ppm., and among the remaining 14 samples total soluble salts exceed 2,000 ppm. in 10 cases (Table 3). These facts are set out in fig. 3.

The areal distribution of water with dominant chloride may be seen on figs. 1 and 2. Waters with dominant chloride tend to occur in areas where precipitation is less than 200 mm. (Table 3); only at Rouad island does a chloride water occur within the + 400 mm. rainfall area, and there its presence is due to contamination of the deep artesian water with some small amount of sea water. Almost all the high chloride waters occur in the zone extending from Zelaf (bore-hole) through Saaba Biar to Palmyra and so around through Soukne and Qasr el Hair (eastern) up to Bir enn Naam and the west bank of the Euphrates. Waters with dominant chloride seldom occur in the Fars Formation or in the limestone aquifers of the higher rainfall areas.

The few exceptions merit brief mention here and will be discussed more fully in the section on "Lithology of aquifers" on page 83. Bir Beghelie, Bir Qasr el Hair (eastern) and Bir Fayadat (nos. 223, 224 and 255) are chloride waters from Fars Formation aquifers. In the first two, chloride only slightly exceeds the sulphate, and indeed the two may be considered as typical Fars waters. At Bir Fayadat, fresh water from Wadi Miah appears to mingle with Fars water, giving rise to an unusual water. From three limestone aquifers, waters with high chlorides have been obtained. At Rouad (no. 118) this is due to contamination by sea-water (fig. 3). The Ain Qenah water from Palmyra (no. 237) is surprising, as it was expected that it would be a sulphate water, coming in contact with the gypsum at the base of the Cenomanian limestone aquifer. Water from the new bore-hole to the north of Zelaf (no. 659) was obtained from Eocene limestone buried under the basalt (fig. 3); as it is located at the edge of the Rhoube depression, it must derive a part of its water by local infiltration.

Seven samples show less than 5 per cent chlorides. Of these, six are from limestone aquifers giving rise to large or very strong springs in the coastal mountains in the region of very high rainfall; almost all come from Jurassic limestones. They include Ain Ouarqa (14), Ain Barada (50), Ain Abou Qbeiss (64), Ain Figeh (288), Ain Ichtebraq (702) and Ain Sinn (703). In some of these waters, the chloride is so low as to be mainly, if not entirely, attributable to "cyclic chloride" of the precipitation. The last water low in chloride, no. 228 from Ain Ekbeibe, comes from one of the larger of the Koum mound springs. These springs are attributed to confined waters rising from Rmah Chert aquifers; while the low chloride content is due mainly to the very high sulphate content, the presence of this unusual water at Koum suggests that it may be incorrect to attribute it to the Rmah Chert aquifer.

Mixed waters of Syria

There remain 11 waters which are classified as "mixed", since in them no one anion exceeds 25 per cent of the total ions (Table 2). In three of them the Mg cation exceeds 25 per cent, but in the other eight no cation or anion is dominant. They are transitional types of water, in which the metasomatism of the primary bicarbonate waters into the final chloride waters is in progress but has not been achieved. At the same time, calcium yields place to sodium, but in the intermediate stage magnesium may temporarily become the dominant anion.

The transitional character of these waters is still more marked when their total soluble salts are considered. With the exception of the one sample from Bir Resafe (no. 247), the others range from 516 ppm. to 1,531 ppm. of total soluble salts. Their intermediate position between the waters with low total solids and those with high total solids is emphasized in fig. 3, where the 10 are enclosed within a dotted line. The intermediate position of this group, when viewed from the point of view of their total soluble salt content, is proof that they are intermediate or transitionary in their varying percentages of the anions and cations which form the total salt content of each of these waters.

The distribution of these waters can be seen from fig. 5, where the 11 numbers referring to them are underlined. It will be seen that they lie in regions which have from 330 mm. (at Tell ett Toute) to 110 mm. (Arak) average annual rainfall. Four of them have more than, and seven of them less than, 200 mm. of average annual rainfall (Table 3). From figs. 1 and 2 it is apparent that they tend to concentrate around Palmyra, extending to Wadi Miah to the east-south-east, to Tell Mahdoun on the north-north-west and to Tell ett Toute west-north-west; they also occur at Bourak and Jairoud around Damascus. But from the point of view of their areal distribution, the principal fact is that they are not found in areas with more than 350 mm. of rainfall.

Special types of water from Syria

While the special types of water are usually closely connected with the composition of the aquifer through which they pass, nevertheless a brief glance at some special waters from the viewpoint of their chemistry alone is of interest.

Sodium bicarbonate waters are part of the bicarbonate group; they occur where sodium is more readily leached than calcium from rocks under attack by bicarbonate-rich precipitation. Thus they are found in waters from primary igneous rocks, such as granites and basalts. In Syria they are characteristic of basaltic waters (nos. 26, 88 and 186).

Magnesium bicarbonate waters might be expected from dolomites and dolomitic limestones. They do not occur,

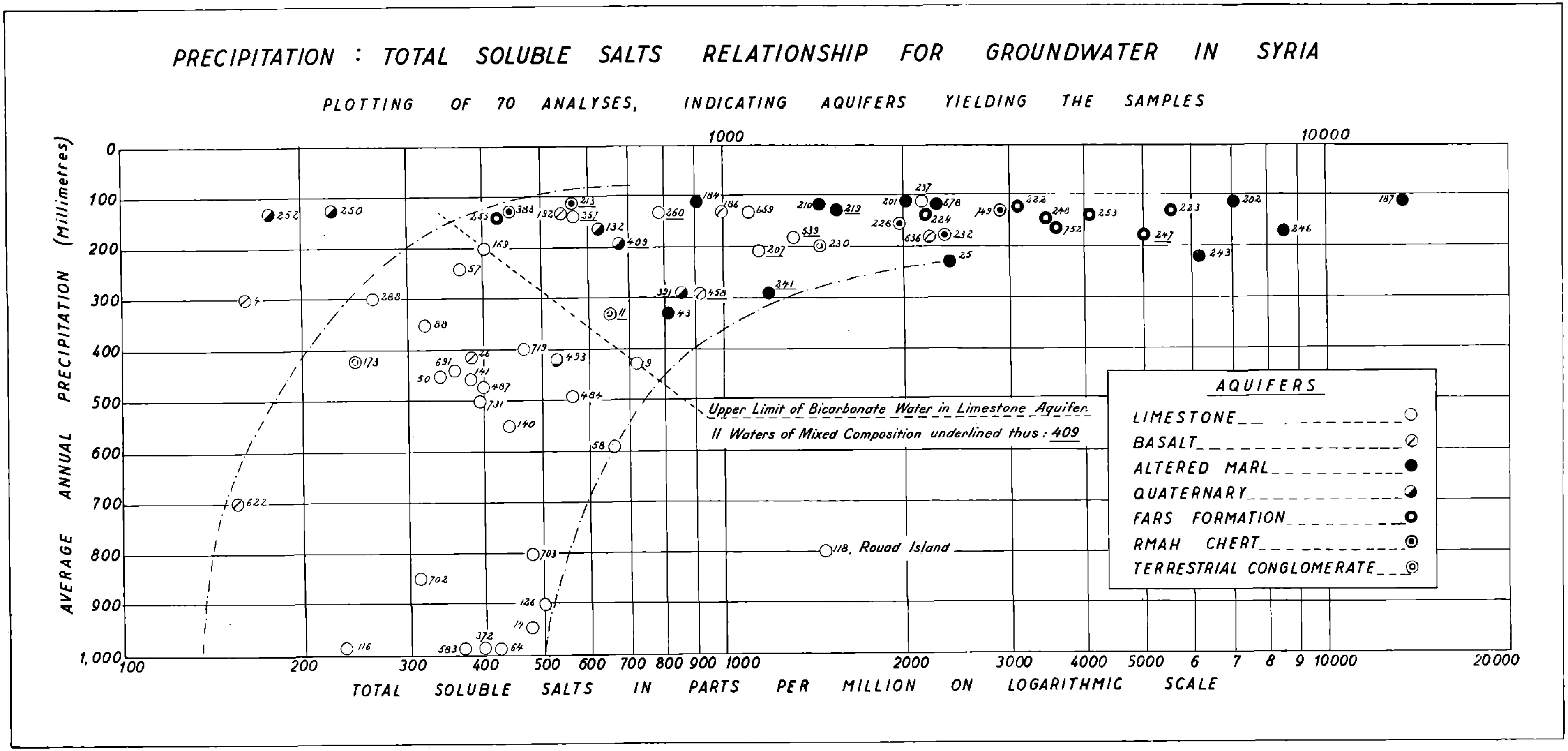

Fig. 5. Relationship between average annual precipitation and total soluble salts for 70 samples of ground-water from Syria. The precipitation is for the area in which the ground-water sample was collected and so may differ from the precipitation over the infiltration-recharge area. Ornamentation on the circles indicates the lithology of the aquifer from which the water was obtained.

since dolomite is much less soluble than calcite, and the mineral magnesite, which is soluble, does not occur in nature when it has calcite with which to react to form dolomite. On the other hand, magnesium sulphate and magnesium chloride are very soluble, and magnesium can become a major constituent of some sulphate or chloride waters. As Table 2 shows, magnesium bicarbonate water does not occur in Syria.

Sodium sulphate water is also rare; it is reported only from Bir Joub Jalib (no. 253), in the general region where the sweet waters of the main drainage wadies of south-east Syria mingle with the saline waters of the Fars Formation.

FACTORS CONTROLLING THE CHEMICAL COMPOSITION OF THE GROUND-WATER

Chemical composition of the precipitation

Precipitation is never pure H_2O; it always contains some ions in solution. The concentration of these ions may be greatly increased by evapotranspiration between the time the precipitation falls and the time at which it infiltrates and recharges the ground-water aquifers [4].

Data on the chemical composition of precipitation in Syria is meagre. Two samples of snow (nos. 808 and 809) were collected from the crests of the Lebanon and Anti-Lebanon mountains on 7 and 8 December 1957. They were analysed only for chlorine, which in both cases was reported as 3 parts per million. This is a very normal figure for precipitation. From comparisons with full analyses elsewhere in the world [22, table 7.4; 17, pp. 231–239; 12], it is likely that the corresponding total soluble salts should be between 15 and 25 ppm. It seems reasonable to assume that over Syria, average precipitation contains 20 ppm. of total soluble salts, of which 3 ppm. are of chlorine.

The concentrations by evapotranspiration of these original salts in the precipitation can be very striking and important. For Syria west of the Euphrates, the new Unesco "Potential Evapotranspiration" map[1] shows that the potential evapotranspiration ranges from 1,140 mm. in the Abou Kemal region to a little less than 855 mm. in the Alouites, Djebel Druse, and Djebel Bilas north-west of Palmyra. Combined with the rainfall, this results in a mean annual water deficit[2] ranging from over 1,000 mm. in the Abou Kemal region to less than 400 mm. in the Alouites, parts of the Anti-Lebanon and in the Djebel Druse. Throughout most of the area considered here, the mean annual water deficit is around 700 mm.

Actual investigations into evapotranspiration losses in the Yarmouk Basin show that losses amount to 80 per cent of the total precipitation [1]. Here the mean annual precipitation is about 415 mm. and the annual water deficit still about 450 mm. These figures might be extended to cover most of Syria where rainfall exceeds 400 mm.; but in the low rainfall areas, evapotranspiration losses must amount to 100 per cent in many years. Only in exceptionally heavy rains can there be appreciable recharge to the aquifers.

It is clear that when primary precipitation contains 20 ppm. of total soluble salts, and where evapotranspiration amounts to 80 per cent, then the salts are concentrated in the balance of the water available for recharge and run-off, so as to amount to 100 ppm. in these waters. Likewise, where evapotranspiration amounts to 90 per cent the remaining water will carry total soluble salts to the extent of 200 ppm. Thus, in a semi-arid region such as Syria, the recharge waters reaching the aquifers may carry from 50 to 200 ppm. of total soluble salts [4]. It is clear that the waters from the basaltic aquifers at Ain Keynia (160 ppm.) and from the Jaba bore-hole (154 ppm.) may almost represent the composition of the original precipitation with little salts added from the aquifers. Both these waters occur in regions of high rainfall; but it is surprising to note that the last of the three waters with less than 200 ppm. comes from the alluvium of Wadi Souab (175 ppm.), which flows through one of the most arid areas in Syria, that around Abou Kemal.

In regions where evapotranspiration amounts to 100 per cent of the precipitation, all the soluble salts are precipitated and crystallize on or near the surface of the ground. Some of these precipitates will form relatively insoluble minerals, such as calcite, dolomite, gypsum or anhydrite; others will occur as readily resoluble salts, such as halite, epsomite and glauberite. Some of these ions or minerals may react with soil minerals through base-exchange and replacement. In this way, exceptionally heavy rainfall may lead to the recharge water taking back in solution ions precipitated in the past, with the result that it contains many salts in solution. In particular, chlorides may be high, for chlorine is not readily held in the soil. But sodium may be held by base-exchange for calcium in many clay minerals. In these, and associated ways, the composition of the recharge to the ground-water may be of a rather unusual chemical composition and of a concentrated nature; while these changes have not been studied in detail, they may be expected to give rise to some unusual types of ground-water in the arid regions.

The general relationships between the chemical composition of the ground-water and the amount of precipitation are summarized in Table 3. Here it is clear that bicarbonate waters predominate in the regions of higher rainfall; whether this is due entirely to the rainfall or mainly to the location of the carbonate aquifers in the regions of high rainfall, while the aquifers rich in soluble salts (in particular the Fars Formation) occur in regions of low rainfall, is not certain. Both play a part, with the lithology of the aquifer more important than the amount of rainfall.

Table 3 also shows the relationship between total soluble salts and the anion composition of the ground-

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[1] Sheet B. 3–6: APE, Red Sea.

[2] Sheet B. 3–6: AWD, Red Sea.

TABLE 3. Relationships between the dominant anion and precipitation and between dominant anion and total soluble salts in 70 samples of ground-water from Syria west of the Euphrates river

	Chemical composition of the ground-water				
	+ 25% HCO_3	+ 25% SO_4	+ 25% Cl	Mixed anions	Totals
Precipitation					
+ 400 mm.	21	0	1	0	22
200–400 mm.	7	1	3	4	15
-200 mm.	6	8	12	7	33
Totals	34	9	16	11	70
Total Soluble Salts					
-500 ppm.	25	0	1	0	26
500–1,000 ppm.	9	1	1	6	17
1,000–2,000 ppm.	0	0	4	4	8
+ 2,000 ppm.	0	8	10	1	19

water. This relationship has been shown in fig. 3, where the plotting of total soluble salts is directly against variations in the relative percentages of HCO_3 and Cl. The actual plotting of total soluble salts against precipitation has been made in fig. 5, and the results are clear, if not particularly instructive. All the samples with more than 1,000 ppm. of total soluble salts lie in regions with less than 300 mm. precipitation. The exception is at Rouad bore-hole, which is explained by some mingling of seawater with the fresh water of the limestone aquifer. On the other hand, in the regions where rainfall exceeds 750 mm., it would seem that the water in the limestone aquifers will contain from 200 to 500 ppm. of total soluble salts. In fig. 5, this sub-group is represented by eight samples; they are all strongly bicarbonate waters.

Lithology of the aquifers

The best correlation between outside factors and the chemical composition of the ground-water has been obtained by a study of the aquifers. The aquifers have a major or dominant influence on the composition of the water which passes through them: *Tales sunt aquae, qualis terra per quam fluunt.* The general characteristics of the relationship are summarized in Table 4, and the influence of the aquifers has been shown in figs. 3 and 5 by indicating by the ornament on the circles from what type of aquifer each water sample has come. Sometimes an abnormal water indicates contact with other aquifers than that from which it was finally obtained; sometimes abnormal chemical composition indicates contamination with water from another source. This section of the paper is subdivided to permit of a description of the waters according to the seven lithological types of aquifer from which they have been derived.

Lacustrine marls and other Quaternary aquifers. From the lacustrine marls comes Nechabye (no. 132) in the Damascus Ghouta, the IPC bore-holes at Fourqloss (no. 391) and the main *fogarra* at Jairoud (no. 409). In fig. 5 these three samples lie close together, with the least soluble salts in the one from the region of least rainfall (Damascus); this is due to the fact that the Ghouta ground-water comes from a region of high rainfall and is not infiltrated local precipitation. In fig. 3 the three samples show the change from a calcium bicarbonate water through a magnesium water with mixed anions to a sulphate water with mixed cations as the total soluble salts increase; these are standard changes in the metasomatism of ground-water within a single type of aquifer. Such lacustrine marls show dominant calcite minerals, but as they were formed in inland basins of closed drainage, gypsum and salts of sodium and magnesium are also likely to occur. Thus, they form a suitable environment in which to study changes in the composition of the ground-water.

The remaining two samples (nos. 250 and 252) come from Quaternary wadi alluvium in some of the great wadis draining towards the Euphrates north of Abou Kemal. These wadis appear to have been washed clear of salts in the Pluvials, and to have remained free of salt accumulations to the present day. Their waters are perfect examples of primary waters, still bicarbonate in character and with low total soluble salts, in a region of low (say, 125 mm. to 130 mm. per annum) rainfall. They have retained their character, since the wadi gravels, apparently mainly limestone-chalk-flint pebbles, do not contain much readily soluble sulphates or chlorides.

Limestone aquifers. Of the 28 samples of water drawn from limestone (which also embraces dolomitic limestone and dolomite), 21 show dominant bicarbonate. Of the remaining 7 samples, 4 are of mixed waters and 3 are chloride waters; there are no sulphate waters from limestone. Likewise, only 5 of the 28 samples show more than 1,000 ppm. of total soluble salts. Of course, limestone aquifers, composed mainly or entirely of calcite and dolomite with some quartz, are particularly likely to produce calcium bicarbonate waters; magnesium bicarbonate waters are extremely rare, due to the low solubility of dolomite and the rarity of magnesite in limestone terrains. But it is also clear in Syria that the limestone aquifers tend to occur in the regions of higher rainfall, as shown in fig. 1. Under these circumstances, it is better to study first the exceptions, and then the normal or more usual types of water found in the limestone aquifers.

Sodium chloride waters occur in 3 limestone aquifers; sample no. 118 from Rouad, with 1,484 ppm.; no. 237 from Ain Qenah at Palmyra, with 2,142 ppm.; and no. 659 from Zelaf bore-hole, with 1,103 ppm. The reasons why chloride waters occur in these limestones have already been explained in the section "Chloride waters of Syria" on page 79. But it is of interest to note how much information is given by the chemical analysis of each of these waters, especially when individual results are compared with averages for the limestone aquifers. And it is also clear how sharply these waters are distinguished from those from other limestone aquifers. In fig. 3, and more especially in fig. 5, the abnormal nature of the water from the Rouad artesian bore-hole is strikingly clear. It is unmistakeable evidence that the casing has not completely sealed-off the water of the deep Turonian aquifer from the brackish water found in the consolidated Pliocene or Quaternary sand-dunes which now rise above the sea to form Rouad Island. Again, the high NaCl content of water from Zelaf bore-hole, especially when compared to the water from Bir Zelaf (no. 192), shows that in part this water in the bore-hole is due to local infiltration. This may occur after a flood in the wadi, when the Rhoube depression may be converted into a temporary lake, and infiltrating water takes into solution halite and other salts found in the clay cover of the depression.

Mixed waters, with no dominant cation or anion, account for four waters found in limestone aquifers, sample no. 207 from Esriye well, with 1,142 ppm.; no. 260 from Bir Tairariye, with 775 ppm.; no. 257 from the IPC bore-holes in Wadi Miah, with 550 ppm.; and no. 539 from Dmeir bore-hole, with 1,314 ppm. Clearly this group, both in percentage composition (fig. 3) and total soluble salts (figs. 3 and 5), is intermediate between the sodium chloride group and the bicarbonate group. Here, however, the changes seem to be due not to admixtures of other waters or to the passage of the ground-water through some other saline aquifer before reaching the limestone, but to the standard metasomatic changes which occur in ground-water. Since the bicarbonate content of ground-water is due mainly to carbon dioxide entrapped in the infiltrating precipitation from the atmosphere and from the zones of infiltration and aeration, and since it almost never has a chance to increase at depth, additional salts are either sulphates or chlorides. Thus, even in a limestone-dolomite aquifer, the bicarbonate content of the water quickly reaches a maximum, and any further increase in total soluble salts involves a decrease in the percentage of the bicarbonate present.

Of the 21 bicarbonate waters in limestone aquifers, it will be noted that in only 4 does the calcium content drop below 25 per cent. These comprise no. 169 from Ain Fasraya in the Ghouta; no. 484 from Dana bore-hole; no. 702 from Ain Ichtebraq; and no. 719 from Taftanaz bore-hole. Ain Fasraya resembles Ain Qenah at Palmyra; both waters may have come in contact with gypsum and precipitate salts at the base of the Cenomanian. Both Dana and Taftanaz bore-holes get water from the Miocene limestone, which is likely to be associated with gypsum beds or molasse sediments; the composition of this water merits further study. Ain Ichtebraq may draw water from dolomitic limestones or dolomites; this might explain its comparatively high magnesium content.

This leaves 17 waters of calcium bicarbonate type, or just over 60 per cent of the 28 samples from limestone aquifers. They all occur in regions with more than 200 mm. of precipitation, and their total soluble salts range from 230 ppm. to 560 ppm.; as may be seen from fig. 5, the range of the total soluble salts appears to be independent of the precipitation. Fig. 5 also shows how a line can be drawn separating bicarbonate waters from the other types of water found in limestone aquifers. The position of this line can be only approximate, but it marks a place where metasomatic processes within the limestone aquifers start to reduce the bicarbonate anion to below 25 per cent of the total ions present. It would appear that the position of this line is influenced as much by the amount of precipitation (200–400 mm. zone) as by the *increase* in total soluble salts in the water.

Basalt aquifers. Eight samples have been selected from basaltic aquifers. In six of these, bicarbonate is the dominant anion, and in three cases sodium is the dominant associated cation. Thus sodium bicarbonate water is the type water of the basalts (see section "Special types of water from Syria", above) and is represented here by sample no. 26 from Mzeirib spring, no. 88 from Dama bore-hole and no. 186 from the well at Djebel Sais. Sodium bicarbonate waters develop in basaltic aquifers because the basalt yields sodium more readily than any other cation when under attack and decomposition by infiltrating precipitation. While plateau basalt contains only 2.59 per cent Na^+ and 0.69 per cent K, as against 9.38 per cent Ca and 6.70 per cent Mg [8], nevertheless much of the calcium and almost all the magnesium is held in the pyroxenes, whereas most of the sodium and potassium is found in the plagioclase feldspars, where, of course, it is associated with calcium. Under late hydrothermal alteration, and in the zone of weathering, the plagioclase breaks down by the process known as saussuritization, in which the original igneous mineral is replaced by an albite-epidote-chlorite-calcite mixture or mat, which is a stable mineral assemblage or facies under normal surface conditions. In these changes, it would appear that sodium is released more freely than calcium or the little magnesium present. Accordingly, sodium tends to become concentrated in the water, as compared to its concentration in the parent rock.

However, in other bicarbonate waters from basaltic aquifers no cation may be dominant, as at Ain Keynia in the Djebel Druse (no. 4) and at Bir Zelaf (no. 192). Sometimes calcium can become a dominant cation, as in the water from Jaba bore-hole (no. 622), which with only 154 ppm. of total soluble salts is the least mineralized water analysed in Syria. Jaba lies near Qnaitra, and has some 700 mm. of precipitation.

In two samples, bicarbonate is not dominant. One comes from Bourak bore-hole (no. 458) and the other from Tell Asfar bore-hole (no. 636). In both cases, it is highly probable that the water has travelled for long distances, and taken much time in so doing, through the basaltic aquifers; and in both cases, it seems likely that the ground-water has come in contact with water from other aquifers, or passed through other aquifers, which could well be lacustrine marls. These two samples have done much to increase the average total soluble salts to 710 ppm. (Table 4); excluding them, the remaining six samples average only 425 ppm. of total soluble salts.

Finally, it should be noted that in the basalts of Syria, waters with high nitrate contents, and sometimes associated high potassium, have been found. They seem to be due to leaching of buried caliche deposits, or to present-day contamination.

Conglomerates and other terrestrial aquifers. Conglomerates of Neogene age are common as infillings of intermontane depressions in Syria; they originated from the heavy erosion of the Oligocene-elevated hills, mountains and horsts. While laid down in inland—and presumably closed or semi-closed—basins, they do not contain evaporites or even many precipitate salts. They would seem to have originated under mechanical rather than chemical weathering (arid conditions?), yet to have been deposited from torrential floods. The waters now found in them are very varied in composition, but seldom high in total soluble salts.

As Table 4 shows, two of the waters are bicarbonate types, one has no dominant anion, and one has Cl dominant. Of the bicarbonate waters, no. 173 from Ras el Ain near Rankouss is very similar to a limestone water; no. 58 from Tell Aayoun in the Ghab has a composition which suggests that the water originated in the Middle Cretaceous limestones to the south and south-east [2]. These two waters present no unusual problem. Nor does no. 11 from Tell ett Toute, near Selemiye; in this water there is no dominant anion or cation, and total soluble salts are 653 ppm. The final water from Neogene conglomerates comes from Bir Kdeim (no. 230) and here chlorides are dominant.

TABLE 4. Relationship between the lithology of the aquifer and the chemical composition of the enclosed water, as expressed by total soluble salts and dominant anion, for 70 samples of ground-water from Syria west of the Euphrates river. Arranged according to increasing amounts of average total soluble salts found in the waters

Aquifer	No. of samples	Total soluble salts			Dominant anion			
		Min.	Average	Max.	HCO_3	SO_4	Cl	Mixed
Quaternary	5	175	514	877	3	1	0	1
Limestone	28	235	617	2 142	21	0	3	4
Basalt	8	154	710	2 215	6	1	0	1
Terrestrial	4	245	750	1 450	2	0	1	1
Rmah Chert	5	436	1 652	2 926	1	3	0	1
Fars Formation	8	426	3 434	5 571	0	4	3	1
Altered marl	12	809	3 983	13 536	1	0	9	2
Totals	70	—	—	—	34	9	16	11

The four samples mentioned show normal metasomatic changes in ground-water within a uniform aquifer. As total soluble salts increase from 245 ppm. at Ras el Ain through some 650 ppm. at Tell Ayoun and Tell ett Toute to 1,450 ppm. at Bir Kdeim, so does the water change from a calcium bicarbonate water, through a bicarbonate and intermediate water to a chloride water at Bir Kdeim. These changes may be seen in fig. 3. The relationship between total soluble salts and precipitation is shown in fig. 5; it may be seen that within this type of aquifer there is a general increase in total soluble salts as rainfall decreases. To this, sample no. 58, from Tell Aayoun, is an exception, and this may be due to the fact that infiltration areas for the Tell Aayoun ground-water may be as far distant as the Djebel Choumariye.

Rmah Chert aquifer. The Rmah Chert is a formation of cherts, flints and dolomitic limestones which occurs within the Senonian marl series little above the top of the Turonian limestones. These hard rocks form prominent outcrops within the soft marl series. They fracture easily and give rise to a surprisingly large number of springs in the folded steppe region of Syria. The ground-water is of intermediate chemical composition, with a strong tendency for sulphate to be the dominant anion and with total soluble salts averaging 1,652 ppm.

Five samples have been selected from the Rmah Chert aquifer. Though they are all from regions with less than 200 mm. precipitation, their total soluble salts range from 436 ppm. at Ain Qariateine to 2,926 ppm. in Wadi Trefaoui bore-hole. Here again, as total soluble salts increase, the composition changes from a bicarbonate water at Qariateine, through an indeterminate water at Arak *fogarra* (561 ppm.) to sulphate waters with dominant calcium at Koum (1,976 ppm.), with no dominant cation at Soukne (2,363 ppm.) and with dominant magnesium at Wadi Trefaoui bore-hole.

The sulphur which is common in the waters must be derived from pyrites associated with the flint-chert. As the iron pyrite oxidizes, some of the liberated sulphur reacts to form gypsum, but some goes into the water. It will be noticed that 3 out of 5 of the Rmah Chert waters contain dominant sulphur; thus with 60 per cent containing dominant sulphur, these waters are the main sulphur-bearing ground-waters of Syria west of the Euphrates.

Fars Formation aquifer. Considering their location in the region of lowest rainfall, and the fact that they are in great part lagoonal and evaporite sediments, it is surprising to find that waters from the Fars Formation are not the most mineralized waters in Syria. This is due to the fact that they are reasonably permeable aquifers, with a fair percentage of communicating voids (solution of gypsum, anhydrite and cementing salts; presence of sands and gravels), so that infiltrated water can move through them to a point of discharge. Thus the ground-water is not trapped and held in intimate contact with soluble minerals for indefinitely long periods. There is active movement of ground-water in the aquifers of the Fars Formation.

All except one of the eight samples from the Fars Formation contain more than 2,000 ppm. of total soluble salts; the exception is at Bir Fayadat (426 ppm.), where fresh water appears to mingle with normal Fars water. However, although the percentage of chlorides in these waters clearly increases, as does the total soluble salt content, according to the standard metasomatic process, the presence of much calcium sulphate removes these waters from the "Major line of descent" of fig. 4 and tends to place them in the "Minor line of descent". This is very clear in fig. 3, and is indicated by enclosing the seven typical, or normal, Fars waters within a dotted line. It is unnecessary to point out that these waters follow the minor line due to the abundant gypsum-anhydrite in the Fars Formation.

Two exceptions are to be found. Bir Fayadat (no. 255) has already been explained, both here and in the section "Bicarbonate waters in Syria" on page 78. At Bir Joub Jalib (no. 253) an unusual sodium sulphate (glauberite) water occurs. It appears to be a mixed water, intermediate between the sodium chloride waters to the east (e.g. Bir Jfeifa), the sweet waters to the south (e.g. Wadi Souab) and the normal Fars water to the north (e.g. Bir Heil).

Altered marl aquifer. Marls, marly chalks and marly limestones are impermeable when fresh. Weathering, however, renders them porous and slightly permeable by attacking the calcium minerals and organic remains, by oxidizing the pyrite-marcasite which they contain and by opening up cracks and joints. Such weathering is active down to a depth of about 25 metres, and may show effects as far down as 50 metres. Below this depth, the marls, marly chalks and marly limestones are fresh and consequently impermeable. Accordingly, nappes found in altered marl are superficial, are due in great part to local infiltration and are best developed by means of wells and, above all, *fogarras*. While the porosity of the weathered rock may be large, the permeability is usually small. This, combined with the lack of any structure to induce a large hydraulic head, means that water in the weathered marls only moves slowly through the aquifer. From these characteristics of the aquifer, the waters in the altered marls derive their chemical character.

Only one bicarbonate water (no. 43 from Chiha) is to be found among the 12 selected samples. This sample shows 809 ppm., and while this figure is the lowest from an altered marl aquifer, it is sufficiently high to indicate that all the carbonic acid in the water has already been used in attacking the carbonates in the rock. If more material goes into solution, it will have to be in the form of sulphates or chlorides. It is something of a surprise to find no sulphate waters from the marl aquifers. Sulphides do occur in the marls, and the sulphur freed when they are oxidized reacts with calcium to form secondary gypsum, which is very common as single crystals, sometimes selenite, and even as veins infilling cracks and joints. Two waters, one from Bir Ouirad (no. 219, with 1,513 ppm.) and one from Tell Mahdoun (no. 241, with 1,183 ppm.), show no dominant anion or cation. Likewise, two waters show chlorides dominant but have no dominant cation; they are from Tell Snime (no. 25 with 2,317 ppm.) and Bir Sabaa Biar (no. 184, with 905 ppm.).

Seven out of the 12 samples show dominant sodium chloride; and in all but one case (Ain Abou Fouaris) total soluble salts exceed 2,000 ppm. The origin of the sodium and of the chlorine is not quite clear. Much of it must be cyclic, brought into the area by the precipitation, and concentrated by evaporation after rain and by evapotranspiration after the precipitation had infiltrated; conditions appear favourable for the elevation of water into the evapotranspiration zone by capillary action. Again, many of the samples, and in particular those with very high total soluble salts, such as those from Ej Jouaif well with 13,536 ppm. and Bir Enn Naam with 8,528 ppm., come from areas of closed drainage. Once the sodium chloride is brought into the area in the precipitation, it cannot escape and becomes more and more concentrated in the ground-water. Again, some of the sodium chloride must represent cognate brine trapped in the sediments; marls are normal marine sediments, and do not contain precipitate or evaporate minerals. Such salts of sodium and of chlorine as they yield must come from entrapped sea water, not from crystals of halite or similar minerals.

The normal metasomatic changes in ground-water may also be followed in the waters contained in the altered marl aquifers. From bicarbonate water with low total soluble salts (no. 43), the waters change to intermediate (nos. 219 and 241) or dominant chloride non-dominant sodium (nos. 25 and 184) waters, whose total soluble salts range from 905 to 2,317 ppm. Beyond this, both sodium and chloride are dominant and the total soluble salts begin to range upwards of 3,000 ppm. Ground-water in the altered marl aquifers follows the "Major line of descent" of fig. 4.

Minor factors affecting the chemical composition of the ground-water

There are numerous minor factors which, under the dominance of the precipitational and lithological effects, affect the chemical composition of the ground-water.

In the zone of infiltration, the precipitation may gain much bicarbonate from carbon dioxide released by oxidation of humus and night transpiration from vegetation; in Syria, such sources are not great, though the low humus content of soils in the semi-arid regions is in part due to the rapidity with which it is oxidized. There can be little doubt but that the HCO_3 content of ground-water is generally greater than that of the original precipitation. In its passage through the soil, base-exchange and the effects of colloids will, in general, tend to release sodium to, and extract calcium and magnesium from, the infiltrating ground-water.

Nitrates are sometimes obtained from the soil, fixed there by bacteriological action, by lightning or by the addition of fertilizers; likewise insecticides and other man-applied chemicals can affect the composition of the infiltrating precipitation. Such additions are unlikely to have any but the most local effects on the composition of the ground-water in Syria. Likewise sulphur bacteria may produce surprising changes in the sulphur content of ground-water; they are known to be active at Ras el Ain in Djezirah, but have not been recognized in the sulphur-bearing regions of Syria west of the Euphrates. Nevertheless, they probably do exist there, and may be a reason why the sulphur content of ground-water in certain regions of Syria is surprisingly low.

The effects of saline, saline-alkaline and non-saline-alkaline soils [27] on the rate and composition of infiltrating ground-water has not been studied in Syria. Saline soils seldom reduce infiltration rates, though they will affect the chemical composition of the resulting ground-water; on the other hand, non-saline-alkaline soils are generally highly dispersed and tend to be impermeable. In the Syrian steppe, a hard-pan is developing which reduces infiltration and produces semi-marsh conditions after rain, due to the retention of the water in the uppermost layer of soil.

Laterites do not form in Syria, so there is no selective leaching away of colloidal silica. Nor is there excessive removal of aluminium as compared with silica, though only a few determinations have been made on the materials (silica, ferrous iron and alumina) likely to be removed in the colloidal state by circulating ground-waters.

Relationships between yield, or rate of discharge, and chemical composition of the ground-water have not yet been analysed fully. Within any one aquifer, it is probable that high-yielding springs or bore-holes will give less mineralized water than will low-yielding ones. The quicker the movement of ground-water through an aquifer, the less time it will have to take salts into solution; and the larger the amount flowing, the greater will be the dilution of the salts taken into solution. As has been remarked earlier, one reason for the high mineralization of water from the altered marl aquifer is the very low permeability of such an aquifer.

CONCLUSIONS

The results described in detail in the foregoing sections of this paper may be summarized into general statements concerning the chemical composition of the ground-water in Syria west of the Euphrates. Exceptions to such generalizations must, and do, occur; but they are exceptions and can generally be attributed to some unusual factor influencing the chemical composition of the particular water.

Bicarbonate waters are the primary chemical types of ground-water, in which total soluble salts do not exceed 1,000 ppm. They tend to occur in regions of higher precipitation, but significant occurrences are reported from around Abou Kemal.

Sulphate waters are the intermediary chemical types of ground-water, in which total soluble salts do not exceed 3,600 ppm. They tend to occur in regions of lower rainfall and are somewhat rarer than might be expected in Syria.

Chloride waters are the final chemical types of ground-water, with total soluble salts seldom less than 1,000 ppm., and ranging upwards of 13,000 ppm. They occur in areas of low rainfall and closed drainage; in part, their sodium and chlorine must be due to cyclic salts.

Mixed waters, with no dominant anion, are also intermediate chemical types of ground-water, as is shown by the fact that in Syria their total soluble salts seem to lie between 500 and 1,500 ppm.; they tend to occur in regions with between 300 mm. and 110 mm. average annual precipitation.

The chemical composition of the precipitation may be changed from an initial figure of some 20 ppm. to concentrations of from 100 ppm. to 200 ppm. by evapotranspiration and leaching of precipitates in the zones of infiltration; thus recharge water to aquifers in Syria may contain from 50 to 200 ppm. of total soluble salts.

The chemical composition of the aquifers is the most important factor controlling the chemical composition of the ground-water.

Lacustrine marls and other Quaternary aquifers yield ground-waters which have the lowest total soluble salts, averaging 514 ppm.; they are predominantly (60 per cent) bicarbonate waters.

Limestone aquifers yield ground-waters which average 617 ppm. total soluble salts; they are predominantly bicarbonate waters (75 per cent) and, indeed, calcium bicarbonate waters (60 per cent). It appears that in limestone aquifers the change from bicarbonate to mixed waters occurs where the average annual precipitation falls below 200–400 mm.

Basalt aquifers yield ground-waters which average 710 ppm. of total soluble salts; waters are usually of the sodium bicarbonate type, except where mixed with waters from other aquifers; waters high in nitrates have been found from basalts.

Conglomerates and other terrestrial aquifers yield ground-waters which average 750 ppm. of total soluble salts, and while bicarbonates account for 50 per cent of the samples, waters tend to be of mixed types.

Rmah Chert aquifer yields ground-waters which average 1,652 ppm. of total soluble salts. They are predominantly (60 per cent) sulphate waters.

Fars Formation aquifers yield ground-waters which average 3,434 ppm. of total soluble salts; they are 50 per cent sulphate plus 37 per cent chloride waters. Reasonably active circulation of the ground-water restricts the amount of total soluble salts.

Altered marl aquifers yield the most mineralized ground-waters in Syria, averaging almost 4,000 ppm. of total soluble salts. They are 75 per cent chloride waters, and derive their sodium chloride from cyclic salts trapped in closed drainage basins. Poor circulation in the aquifers tends to increase the total soluble salt content of the waters.

Metasomatism of ground-water can be traced for the ground-waters in most of the aquifers; it is extremely well-marked in the Quaternary, Limestone, Terrestrial conglomerates and in the altered marl aquifers. In this process, as total soluble salts increase, the water changes from a primary bicarbonate water through an intermediate stage when no anion, or the sulphate anion, will predominate, to a final stage where total soluble salts are very high and the chlorides predominate.

Metasomatism of ground-water can be traced over the region as a whole, taking place more rapidly in aquifers with more soluble salts and in regions of low rather than high rainfall. Predominantly bicarbonate waters are found in the Quaternary, Limestone and Basalt aquifers; mixed waters occur in the terrestrial conglomerates and sulphate dominant waters in the Rmah Chert; chlorides become of importance in the mixed waters of the Fars Formation and are completely dominant in the waters from the altered marl aquifer.

CHEMICAL ANALYSES

These were carried out in the following laboratories:

1952. United States Salinity Laboratory, Riverside, California; reported by Wilcox in Table 61/52.

1953. Stazione Chimico-Agraria Sperimentale, Rome; reported by Professor Luigi Marimpietri.

1954–55. Central Government Laboratory, Amman; reported by Dr. J. Habayeb.

1956–57. Laboratory of the Ministry of Agriculture, Damascus; reported by Dr. Amin Sharif.

The authors' thanks are due to the chemists of these laboratories, and trust that they will find of interest the deductions which it has been possible to make from their careful analysis of the water samples.

RÉSUMÉ

Compositions chimiques caractéristiques d'eaux souterraines de Syrie (D. J. Burdon et S. Mazloum)

On a prélevé en Syrie, à l'ouest de l'Euphrate, soixante-dix échantillons d'eaux souterraines qui sont censées être caractéristiques de la région. Cette étude expose les résultats des analyses chimiques intégrales dont ces soixante-dix échantillons ont fait l'objet. Elle donne des indications sur les types chimiques d'eaux souterraines qui existent dans cette partie de la Syrie, sur leur origine et leur répartition. Les principaux facteurs qui influent sur la composition chimique des eaux souterraines sont le régime des précipitations et la lithologie des couches aquifères. C'est ce dernier facteur qui est le plus important; aussi les types normaux et anormaux d'eaux souterraines trouvés dans les sept types lithologiques de couches aquifères de la région sont-ils décrits de façon détaillée.

Cette étude fournit, pour chaque couche aquifère et pour l'ensemble de la région, des indications sur la métasomatose en vertu de laquelle aux eaux souterraines primaires — eaux bicarbonatées ayant au total une faible teneur en sels solubles — se substituent d'abord des eaux sulfatées ou de composition complexe, puis, au dernier stade, des eaux chlorurées à forte teneur en sels solubles. Ce concept métasomatique explique le caractère anormal de bien des eaux souterraines. Les conclusions auxquelles arrivent les auteurs sont résumées en quinze formules qui fournissent des indications générales sur la composition des eaux souterraines de la Syrie à l'ouest de l'Euphrate.

DISCUSSION

G. Drouhin. (1). Je voudrais demander si le remarquable exemple d'analyse chimique des eaux qui vient d'être exposé fait partie d'une étude plus générale d'hydrologie souterraine (consistance des nappes, zones d'alimentation, zones de pertes ou de prélèvements, etc.)?

(2). Les analyses effectuées sont-elles assez complètes pour être reportées sur des diagrammes de Schoeller? S'il en était ainsi, cela faciliterait les comparaisons pour plusieurs d'entre nous.

S. Mazloum. (1). L'hydrologie des eaux souterraines fait actuellement, en Syrie, l'objet d'études méthodiques visant à définir leurs conditions d'alimentation, leurs fluctuations, l'importance des réserves disponibles, etc. L'interprétation des analyses chimiques effectuées constitue un chapitre de cette étude d'ensemble; elle est présentée ici dans le cadre des problèmes de salinité qui font l'objet de ce colloque.

(2). Les analyses effectuées sont complètes, ainsi qu'on en jugera par les tableaux annexés à cette communication, et elles permettront aisément le tracé des diagrammes de Schoeller. Mais la représentation adoptée, dérivant des diagrammes de Durov, fournit une comparaison plus claire de la composition des échantillons.

H. SCHOELLER. (1). Vous parlez de métasomatose. Qu'entendez-vous par là?

(2). Le terme de métasomatose a déjà été employé en géologie pour désigner un tout autre phénomène. Il serait nécessaire de choisir un autre mot.

(3). Le diagramme de Durov détermine chaque eau par un point. Mais l'abscisse du point peut correspondre à plusieurs eaux et il en est de même de l'ordonnée.

S. MAZLOUM. (1). Par "métasomatose", nous entendons le phénomène d'évolution de la composition chimique des eaux. Ainsi aux eaux souterraines bicarbonatées, se substituent souvent progressivement des eaux sulfatées ou de composition complexe, puis des eaux chlorurées à forte teneur en sels dissous.

(2). Si le terme de "métasomatose" a été déjà employé en géologie pour désigner la transformation des sédiments après leur dépôt, on pourrait désigner l'évolution de la composition chimique des eaux par "métasomatose hydrologique".

(3). Je reconnais que le diagramme de Durov représentant chaque eau par un point pourrait donner lieu à une certaine ambiguïté, puisque l'abscisse du point figuratif d'une eau peut correspondre à plusieurs autres compositions alignées sur une même verticale sur le diagramme triangulaire. C'est pourquoi nous avons jugé utile de compléter le diagramme de Durov par les diagrammes triangulaires relatifs aux anions et aux cations, afin de supprimer toute ambiguïté, et tout en bénéficiant du grand avantage de la représentation ponctuelle pour faciliter les comparaisons.

J. H. WHITNEY. If the standards of the U.S. Public Health Service and the U.S. Bureau of Reclamation are adopted, then in Saudi Arabia there are *no* waters suitable for human or animal consumption. However, we know that there is agriculture, and humans continue to use these waters. Are the standards of the two agencies (above) the *only* standards used?

S. MAZLOUM. En dehors des normes fixées par les services de l'hygiène et le Bureau of Reclamation des États-Unis en ce qui concerne la potabilité de l'eau, on peut signaler les normes plus tolérantes en usage en Afrique du Nord (Schoeller).

Cependant, il y a lieu d'observer que les normes définies pour l'Amérique du Nord ou l'Europe seraient difficilement applicables dans les zones arides, où la qualité des ressources disponibles oblige à tolérer l'usage d'eaux moins pures. L'organisme humain finit d'ailleurs par s'adapter à la consommation d'une eau légèrement minéralisée et acquiert une certaine immunité contre ses effets (et lorsque les nomades de la steppe syrienne visitent les centres urbains desservis par une distribution d'eau potable, ils jugent souvent trop fade l'eau pure qui leur est servie!).

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LES EAUX SALÉES AU MAROC

par

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INTRODUCTION

Dans le cadre de ce bref exposé qui constitue un essai monographique préliminaire, on se bornera à dresser un inventaire des facteurs conditionnant la formation des eaux salées au Maroc, des principaux types d'eau salée, des processus chimiques de leur genèse, et des problèmes pratiques qui se posent[1].

D'abord deux précisions:

a) Toutes les eaux naturelles contiennent une certaine quantité de sels dissous: la définition des eaux salées[2] implique le choix d'un taux minimum de concentration, nécessairement arbitraire et relatif au pays, aux qualités optimums des eaux de chaque région ainsi qu'à leurs usages (alimentation ou irrigation). Au Maroc où beaucoup de régions ne possèdent pas d'eau à concentration inférieure à 1 g/l, la qualification d'eau salée s'applique en général aux eaux dépassant 2 g/l de concentration en sels totaux (ou 1 g/l en ion Cl).

b) Le présent essai laisse de côté la question des eaux minérales et thermominérales du Maroc.

FACTEURS DE LA FORMATION DES EAUX SALÉES AU MAROC

Les conditions d'aridité du climat et leurs conséquences hydrologiques sont le facteur fondamental de la formation des eaux salées: si elles sont atténuées par les conditions naturelles en certaines régions, elles sont le plus souvent aggravées par des facteurs secondaires: géographiques, géologiques et parfois humains.

Facteurs climatiques

L'indice pluviométrique moyen global du Maroc est voisin de 240 mm/an (ou 330 mm/an sur 330 000 km^2, en excluant les zones désertiques); il est inférieur à 250 mm/an et la fréquence des pluies est inférieure à 30 jours sur plus de la moitié du pays.

L'évaporation potentielle s'élèverait, d'après les mesures effectuées au Piche, à plus de 2 m/an sur la plus grande partie du Maroc et à plus de 4 m/an sur plus du tiers du pays (régions du sud et du sud-est); mais on sait que les résultats des mesures au Piche sont à diviser par deux pour exprimer plus correctement la réalité. L'évaporation potentielle calculée suivant la méthode de Thornthwaite indique par ailleurs des hauteurs variant entre 0,6 et 1,1 m/an.

De toute manière, l'aridité se traduit indiscutablement par un net déficit des précipitations dont les totaux moyens annuels sont inférieurs à la hauteur de l'évaporation potentielle sur les neuf dixièmes du pays (fig. 1). D'après la classification de Thornthwaite, les deux tiers du Maroc appartiennent à la zone aride, avec un indice inférieur à —40 (fig. 1).

Enfin, le climat est très contrasté: à la saison sèche d'été, générale, s'ajoute une saison sèche d'hiver dans une grande partie du pays.

Le nombre de mois secs est presque partout plus élevé que le nombre de mois humides.

Facteurs hydrologiques

Ils sont la conséquence directe des précédents. D'une part, dans la plus grande partie du Maroc, l'évapotranspiration entre pour une part prépondérante dans le passif des bilans hydrauliques de chaque bassin, ce qui diminue les coefficients de ruissellement appliqués à des hauteurs de pluie déjà faibles.

C'est ainsi que les modules relatifs d'écoulement varient suivant les régions entre 0,2 et 6 l/s par kilomètre carré (Rif excepté); la moyenne pour l'ensemble du pays est voisine de 1. Ils sont inférieurs à 1 dans tout le domaine présaharien et le bassin de la Mou-

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[1] Cf. aussi "Hydrogéologie du Maroc" (XIX^e Congrès géologique international, Alger, 1952).

[2] Terme pris ici au sens large, c'est-à-dire eaux chargées non seulement en ClNa, mais en d'autres sels. Sauf indication contraire, les concentrations indiquées concernent toujours le total des sels dissous (résidu sec).

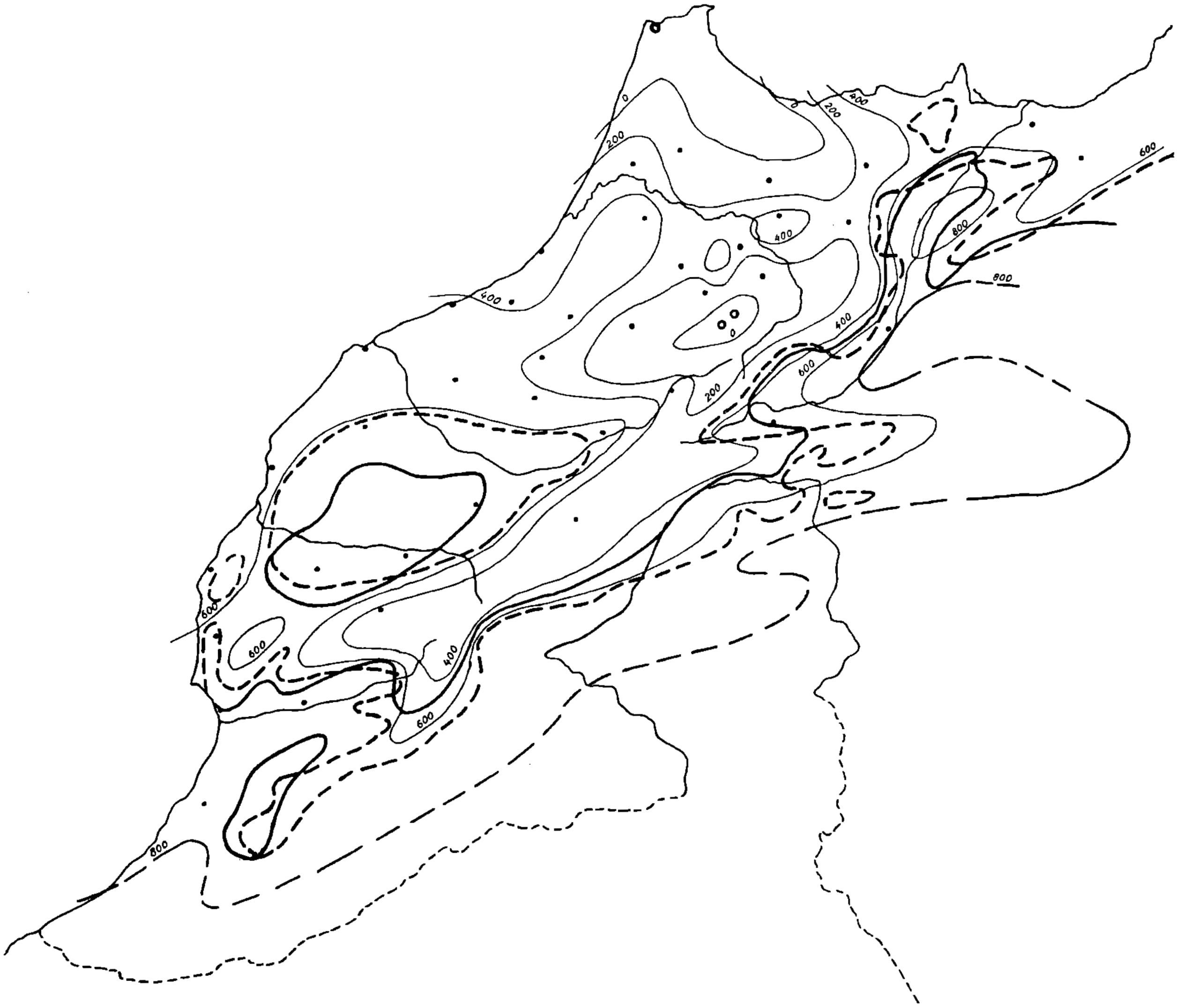

FIG. 1. L'aridité au Maroc. (D'après les documents de J. Debrach, F. Joly, J. Ousset, M. Michel.)

600 Déficit des précipitations par rapport à l'évaporation potentielle (hauteur en mm/an, calculée d'après l'indice de Thornthwaite)

○ Station à bénéfice

• Station à déficit

——— Isohyète de 250 mm/an

— — — Limite de la zone aride, d'après F. Joly (indice de Thornthwaite <—40)

louya et diminuent d'amont en aval dans beaucoup de bassins.

D'autre part, l'irrégularité et la courte durée des écoulements superficiels sont la règle. Malgré la richesse relative du Maroc en fleuves, les cours d'eau pérennes sont peu nombreux: la densité du drainage[1] est de l'ordre de 5 à 100 suivant les régions et inférieure à 10 au sud de l'Atlas. Les autres oueds[2] ne coulent que de quelques jours à quelques mois par an.

Un ruissellement faible (en valeur absolue) et trop discontinu est la cause immédiate d'une concentration en sels des eaux superficielles, nécessairement plus élevée qu'en pays humide, à égale extension de terrains salifères. Les eaux superficielles du Maroc ont une concentration moyenne qui est fréquemment comprise entre 500 et 1 000 mg/l. C'est là un fait très important — bien que ces eaux ne soient pas salées à proprement parler — car de nombreuses nappes souterraines au Maroc sont

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[1] En kilomètres de cours d'eau pérenne par 1000 kilomètres carrés.

[2] "Oued": mot arabe signifiant cours d'eau en général et plus spécialement cours d'eau à écoulement très irrégulier de la zone aride et subaride.

alimentées pour une part sensible et souvent prépondérante par l'infiltration d'eaux superficielles: *la concentration de l'eau de ces nappes est donc plus rapide* que si leur alimentation provenait principalement de la pluie directement infiltrée. C'est le cas notamment dans tout le domaine présaharien, dans le Souss et dans le Haouz.

Le processus est encore plus net si les eaux d'oued infiltrées sont elles-mêmes salées (nappe du nord-ouest du Souss salée par l'oued Issem, du sud du Haouz salée par les oueds Zat et Rdat).

En somme, à l'échelle du pays entier, la mise en mouvement des sels par les eaux de ruissellement ou infiltrées aboutit davantage à leur déplacement qu'à leur évacuation (autrement dit, le lessivage est lent et partiel).

Facteurs géographiques et morphologiques

L'endoréisme. Si l'aridité se trouve diminuée dans les régions montagneuses du nord et du centre du Maroc, plus élevées et mieux arrosées (plus de 500 mm/an, Rif, moyen et haut Atlas), ses effets sont au contraire aggravés par la grande extension de l'endoréisme.

L'endoréisme rigoureux, structural, s'étend dans le sud-est du pays: bassins des chotts, aux confins algériens, bassins sahariens de la Saoura et de la Daoura. De nombreux bassins fermés d'étendues diverses s'y ajoutent sur le versant saharien, mais aussi dans le reste du pays: région orientale (Bou-Houria, Guerrouaou), moyen Atlas et haut Atlas (lacs), bassins occidentaux (Bahira).

Le domaine endoréique s'étend ainsi sur plus de 130 000 km², soit le quart du pays[1], qui échappent rigoureusement au drainage vers la mer (fig. 2).

Un endoréisme "hydrologique", conséquence de l'aridité, s'ajoute aux obstacles structuraux à l'écoulement vers la mer: il résulte de la dégradation fonctionnelle des réseaux hydrographiques de nombreux bassins ou sous-bassins où le ruissellement n'entraîne presque jamais d'écoulement affluant aux collecteurs principaux. Il ne se manifeste pas seulement dans le domaine présaharien où il est de plus en plus net vers le sud (bassins de l'oued Noun, du Dra, certains sous-bassins de la Daoura et de la Saoura), mais aussi dans le Maroc exoréique (sud du Souss, est du bassin de la Moulouya).

Divers facteurs morphologiques, parfois combinés avec les effets de l'aridité, contribuent enfin à entraver le drainage superficiel: aplanissement très poussé et horizontalité de certaines basses plaines littorales (Rharb, Triffa) ou de certains plateaux structuraux (hauts plateaux de l'Oriental, hamadas présahariennes qui constituent des domaines presque "aréiques"); formes dunaires actuelles (domaine présaharien) ou fossiles, très développées dans les régions côtières atlantiques (plio-quaternaire); formes karstiques développées dans le moyen Atlas ou, plus rarement, glaciaires (cuvettes dans le haut Atlas); enfin formes volcaniques récentes (nappes basaltiques quaternaires dans le moyen Atlas).

De nombreuses régions sont ainsi dépourvues de réseau hydrographique organisé.

Ces diverses formes d'endoréisme règnent au total sur *plus de la moitié du pays* (près de 300 000 km²), *où* le coefficient de ruissellement global est quasi nul. Elles concourent donc à localiser les effets du lessivage superficiel qui n'aboutit qu'à concentrer les sels dans les parties basses des bassins fermés ou dans les nappes phréatiques.

On soulignera toutefois que la faiblesse ou l'inorganisation du drainage superficiel n'est pas une cause directe suffisante de salure des eaux souterraines, car elle peut être compensée par des facteurs hydrogéologiques (nappes à écoulement assez rapide); elles aggravent en revanche les processus de concentration lorsqu'elles coïncident avec des conditions hydrogéologiques faisant obstacle à l'écoulement des eaux souterraines (structures fermées, faibles perméabilités).

Plus généralement, le développement du drainage souterrain au détriment du ruissellement superficiel accroît à la fois la régularisation naturelle et les quantités de sels dissous dans une région: par exemple, l'absence presque totale du ruissellement superficiel dans l'ouest du moyen Atlas en raison du développement des cuvettes karstiques et des formes volcaniques n'est pas étranger à la salure de l'Oum er Rebia, dont les sources sont le principal exutoire du drainage souterrain de cette région.

La mer. On ne saurait négliger enfin l'influence directe de la mer: sur près de 50% des côtes méditerranéennes ou atlantiques du Maroc, les eaux des nappes phréatiques littorales sont salées par diffusion ou invasion d'eau marine (fig. 3). Le rôle des marées sur les côtes atlantiques peut y contribuer.

Facteurs géologiques et hydrogéologiques

Facteurs structuraux. La structure géologique du Maroc se caractérise par l'existence de trois grandes chaînes, axes tectoniques et orographiques majeurs, grossièrement parallèles, qui traversent tout le pays du sud-ouest au nord-est (moyen Atlas, haut Atlas, Anti-Atlas) et auxquelles s'ajoute au nord le Rif. Cette structure — accentuée par le développement de bassins d'effondrement dans le nord-ouest du pays — est le facteur principal de l'établissement de l'endoréisme superficiel que l'aridité a contribué à maintenir.

Mais elle a aussi pour conséquence l'existence de nombreux bassins sédimentaires intérieurs qui forment autant de bassins hydrogéologiques fermés ou semi-fermé (sillon sud-atlasique, bassins de haute et moyenne Mous louya, Tadla et Bahira, Doukkala et plaine de Berrechid). Les eaux souterraines de ces bassins (nappes phréatiques ou captives) n'ont que des exutoires superficiels ou occultes réduits, elles se renouvellent lentement; aussi l'influence des niveaux salifères et les processus de concentration sont-ils amplifiés.

Seuls deux bassins importants s'ouvrent sur la mer: le Souss et le Rharb.

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[1] Dans ses frontières de fait actuelles (1958).

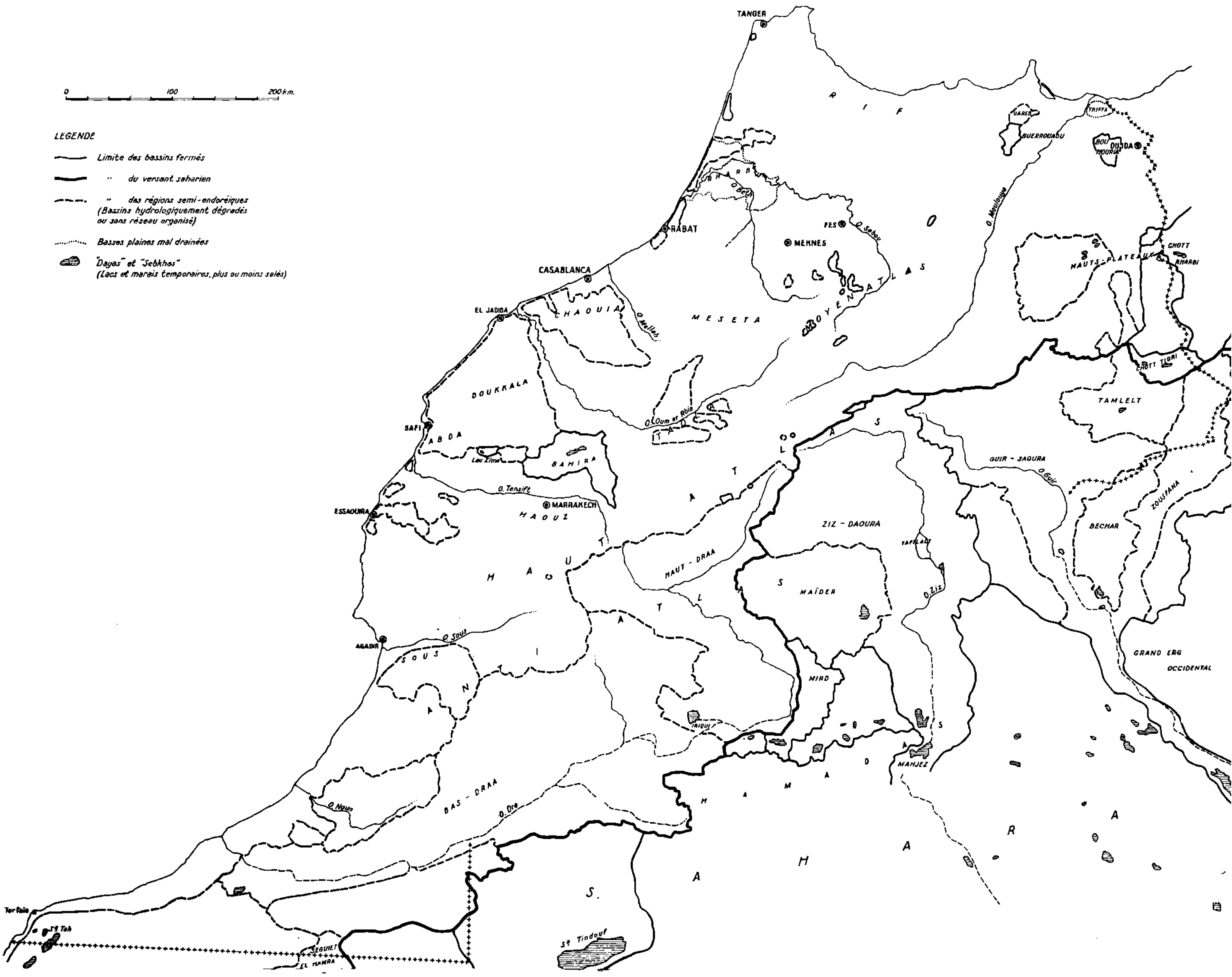

FIG. 2. L'endoréisme au Maroc.

Facteurs lithologiques. L'abondance et la répartition des niveaux salifères est sans conteste une des principales causes directes de la salure des eaux: la richesse du Maroc en terrains salifères aggrave ainsi grandement les conditions climatiques et géographiques qui favorisent déjà la concentration des eaux.

La carte ci-contre et le tableau 1 (p. 97) synthétisent la répartition géographique et stratigraphique des terrains salifères au Maroc. On notera qu'aucune région tant soit peu étendue, hormis la chaîne anti-atlasique, n'est entièrement dépourvue de terrains salifères et que ces derniers appartiennent à de nombreux niveaux géologiques, lagunaires ou continentaux. Le principal est le trias dont les affleurements, rarement très importants, s'observent dans presque tout le Maroc et qui est présent à des profondeurs très diverses dans les quatre cinquièmes du pays.

Les autres niveaux ont une répartition plus régionale et sont parfois très localisés. Une mention spéciale concerne le quaternaire: ses niveaux salifères le sont rarement d'origine et résultent surtout des phénomènes actuels de concentration des eaux et de saturation ou d'évaporation. Mais, localement ou périodiquement, ces niveaux peuvent inversement accroître la salure des eaux, selon des cycles d'échanges saisonniers ou interannuels.

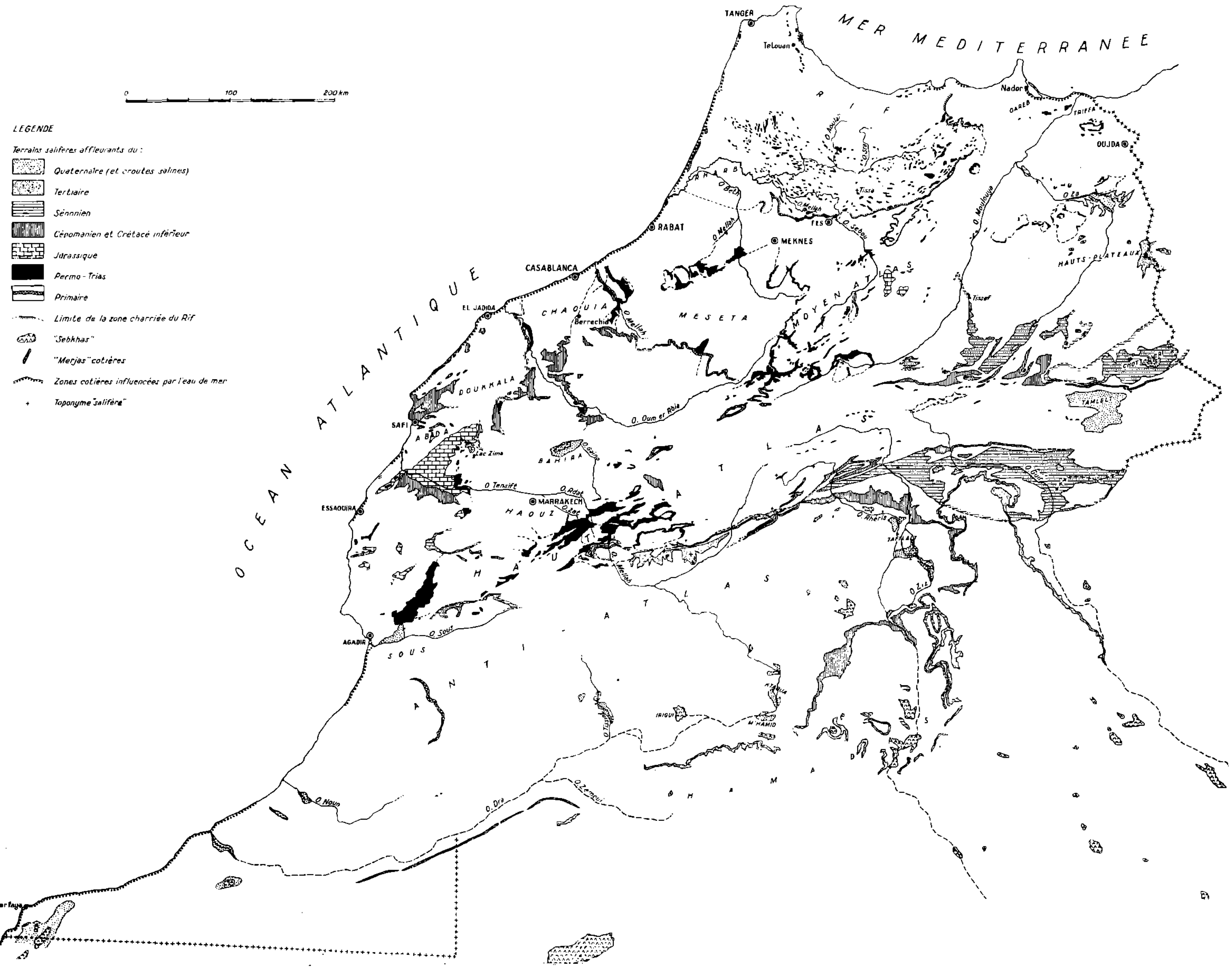

Fig. 3. Répartition des terrains salifères au Maroc. Carte dressée par J. Margat.

Facteurs humains

L'intervention humaine vient enfin aggraver localement les processus naturels de salure des eaux et des sols en certaines régions. Cette intervention se manifeste de trois manières:

a) L'irrigation par des eaux salées, sans drainage compensateur suffisant: c'est le cas dans les Beni Amir (Tadla) par les eaux de l'oued Oum er Rebia, dans le Souss par celles de l'oued Issen, et dans certains périmètres irrigués par eau souterraine pompée (Tafilalet).

b) L'irrigation par épandage massif d'eaux de crue dans les oasis présahariennes entraîne un fort accroissement de l'évapotranspiration réelle dans ces périmètres et accentue la concentration en sels de l'eau et du sol à la périphérie et à l'aval des palmeraies où se développent des croûtes salines ("solontchak"). Les cas les plus typiques s'observent au Tafilalet, où l'on a pu évaluer à 30 000 tonnes l'apport moyen annuel de sels résultant du système actuel d'irrigation dans un périmètre de 20 000 ha.

c) La surexploitation par pompage des nappes phréatiques des zones littorales a provoqué sur de vastes secteurs des invasions d'eau de mer qui rendent ces nappes inexploitables.

COMPOSITION DES EAUX SALÉES DU MAROC

D'après leur composition, on distingue parmi les eaux salées du Maroc plusieurs faciès (cf. tableau 2):

a) Des eaux chlorurées sodiques. Ce sont de beaucoup les plus fréquentes, ce faciès étant normal au Maroc pour les eaux dont la concentration totale dépasse 1 à 1,5 g/l. Leur composition est du type[1]:

$$r\text{Ca} < r\text{Mg} < r\text{Na} \quad \text{et} \quad r\text{CO}_3\text{H} < r\text{SO}_4 < r\text{Cl}$$

sauf si des échanges de bases ont modifié les rapports des cations. Appartiennent à ce type toutes les eaux concentrées par évaporation, les eaux contaminées par la mer et la plupart des eaux de niveaux salifères.

b) Des eaux hyperchlorurées sodiques. Ce sont les eaux très concentrées: plusieurs dizaines ou centaines de g/l. Elles contiennent de 90 à près de 100% de ClNa. Il s'agit soit d'eaux très concentrées par évaporation du domaine présaharien ou de certains bassins fermés (jusqu'à près de 70 g/l), soit d'eaux en contact avec du sel gemme pur (près de 320 g/l au J. Tissa dans le Rif), soit d'eaux connées associées à certains gisements d'hydrocarbures (100 à 400 g/l). Ces dernières présentent souvent des modifications de faciès dues à des échanges de bases (eaux chlorurées calciques) ou à une réduction des sulfates.

c) Des eaux sulfatées. Ce sont surtout des eaux sulfatées calciques (séléniteuses) du type

$$r\text{Mg} \gtreqless r\text{Na} < r\text{Ca} \quad \text{et} \quad r\text{CO}_3\text{H} < r\text{Cl} < r\text{SO}_4$$

Il s'agit d'eaux soit de niveaux gypseux et pauvres en ClNa (primaire, jurassique, éogène, quaternaire), soit en contact avec des terrains où se développe du gypse secondaire (certains schistes primaires pyriteux, marnes et marno-calcaires du jurassique moyen et dans lesquels les eaux circulent assez lentement pour se concentrer par dissolution).

La concentration totale de ces eaux dépasse rarement 5 g/l et jamais 10 g/l (maximum en SO_4: 3 à 3,5 g/l). Il est à noter que les plus concentrées sont cependant moins riches en sulfates que certaines eaux chlorurées (jusqu'à 13 g/l de SO_4 dans des eaux très concentrées où des sulfates plus solubles s'ajoutent au gypse).

Parfois modifié par échange de bases, le faciès de ces eaux devient sulfaté sodique ou magnésien.

d) On ne mentionnera enfin que pour mémoire les eaux à faciès anormal (eaux bicarbonatées sodiques); ce sont généralement des eaux "minérales" ou modifiées par des apports de CO_2 *per ascensum:* on en connaît plusieurs exemples dans l'Anti-Atlas (2 à 3 g/l), eaux fluorées qui, sans être salées, peuvent être impropres à la consommation et sont fréquentes dans les terrains phosphatés qui s'étendent au Maroc dans de vastes régions où une maladie spéciale, le "darmouss", est provoquée par le fluor (jusqu'à 3 mg/l de F).

RÉPARTITION DES EAUX SALÉES AU MAROC

Il faut distinguer, d'une part, de nombreux points où des eaux salées se manifestent de manière plus ou moins localisée, d'autre part, des régions où la plus grande partie des eaux est salée sur de grandes étendues.

Bien que, dans le premier cas, les effets des eaux salées ne soient pas toujours négligeables, des problèmes généraux se posent surtout dans le deuxième cas.

Eaux salées superficielles

Cours d'eau. La plupart des cours d'eau marocains offrent un régime de salinité aux amplitudes assez marquées et variables d'amont en aval.

On distinguera parmi eux des *oueds salés proprement dits,* dont l'eau titre en moyenne plus de 1,5 à 2 g/l sur la majeure partie de leur cours et durant la plus grande partie de l'année; elle n'est adoucie que lors des crues d'hiver ou de printemps, tandis que la salure maximum des oueds pérennes se produit à la fin de l'étiage d'été. L'extension des affleurements triasiques dans leur bassin versant est à l'origine des principaux oueds salés du Maroc: l'oued Mellah au nord-ouest, l'oued Serrou, affluent de l'Oum er Rebia, dans le moyen Atlas, les oueds Zat et Rdat, affluents du Tensift, l'oued Issen, affluent du Souss, et l'oued Mellah, affluent de l'oued Ouarzazate, dans le haut Atlas; enfin de nombreux oueds du Rif affluents de l'Ouerrha: oued Aoulai (maximum 12 g/l), oued Sra (maximum 5 g/l), oued Aoudour (maximum 3 g/l).

D'autres oueds sont salés, dans le domaine présaharien, par le lessivage de terrains salifères quaternaires et de croûtes salines permanentes: c'est le cas de l'oued Tissint (jusqu'à 15 g/l) et de plusieurs autres affluents du Dra inférieur et de l'oued Noun dans son cours aval (jusqu'à 24 g/l).

Au lessivage des terrains salifères affleurants par les eaux de ruissellement s'ajoute parfois l'influence de sources salées, lorsque leur débit est important: c'est le cas du seul grand fleuve du Maroc dont les eaux soient salées sur un grand parcours en période d'étiage, l'Oum er Rebia, salé par ses sources (3 g/l) et par certains affluents comme l'oued Serrou, et de quelques oueds rifains comme l'oued Lebene, où l'influence de sources salées est plus localisée.

Il existe, d'autre part, des *oueds à salure saisonnière* se produisant au début de l'automne, à la suite du lessivage des encroûtements salins estivaux par l'eau des premières pluies. C'est le cas de la plupart des oueds de la zone aride et subaride du Maroc: la Moulouya (eau dont la salure atteint 1,2 à 2 g/l en septembre près de son embouchure), et les oueds sahariens. Lors des premières crues d'automne, l'eau de l'oued Ziz peut atteindre 2,3 g/l et celle de l'oued Rheris, 4,7 g/l.

Lacs. Les lacs sans émissaires sont nombreux au Maroc. Aux "dayas" et "aguelmanes" du moyen et du haut Atlas, à l'eau généralement douce, s'opposent les "sebkhas" du domaine présaharien et des "chotts" du

[Suite à la page 102]

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[1] r = expression en équivalent.

TABLEAU 1. Stratigraphie et répartition des terrains salifères au Maroc

Stratigraphie	Lithologie (faciès salifères)	Sels	Répartition géographique	Caractères hydrogéologiques	Concentrations maximums observées des eaux (résidu sec)
Quaternaire	Alluvions fluvio-lacustres (limons et argiles), dépôts de sebkha, croûtes salines (solontchak) (dépôts actuels ou subactuels)	ClNa (surtout en surface) ou gypse	Plaine du Rharb, cuvettes fermées type lac Zima; chotts du sud-est. Plaines présahariennes (bassins du Tafilalet, du Dra, etc.)	Nappes phréatiques à bilan hydraulique déficitaire	6 g/l 10 à 70 g/l suivant les bassins
Néogène continental	Marnes et grès	Gypse, ClNa plus rare	Hauts plateaux, bassin de Berguent, hamadas, sillon sud-atlasique		
Pliocène marin	Grès coquilliers et conglomérat	ClNa	Plaines côtières atlantiques (niveaux salifères discontinus et localisés)	Nappes phréatiques	2 à 8 g/l
Miocène marin	Marnes et argile	ClNa	Rharb et Mamora		
Oligocène continental	Marnes et gypse	Gypse	Localisé: hamada Boulaouiche		
Eocène continental	Marnes et grès gypseux	Gypse	Localisé: moyen Atlas ("couches de Feleddi")		
Crétacé supérieur:					
Maëstrichtien	Phosphates et marnes phosphatées	Fluorures	Plateau des Phosphates, Bahira	Nappe phréatique discontinue	3 mg/l de F
Sénonien lagunaire ou continental	Calcaires gypseux, grès et marnes rouges, sel gemme	ClNa plus rare, gypse (non associés en général)	Bassins sud et nord-atlasique, hauts plateaux orientaux, chott Tigri, bassin de Zegdou	Nappes phréatiques discontinues	3 à 10 g/l
Crétacé moyen:					
Cénomanien (base)	Argiles bariolées	ClNa, gypse	Bassins sud et nord-atlasique, Doukkala	Imperméables	
Crétacé inférieur:					
Infracénomanien	Grès, argiles et marnes rouges, anhydrite	Gypse, anhydrite	Bassins sud et nord-atlasique, plateau des Phosphates, plaine de Berrechid, Abda (nord de Safi)	Nappes captives discontinues	3 à 15 g/l
Néocomien	Calcaires marneux	ClNa, gypse	Doukkala	Nappes captives discontinues	2,5 g/l
Jurassique supérieur	Grès rouges continentaux, calcaires, marnes et marnocalcaires lagunaires, gypse	Gypse	Doukkala, Abda (régions de Safi et Louis-Gentil) Bassin de Mogador, haut Atlas occidental (localisé)	Niveaux aquifères discontinus Nappes captives localement	5 g/l

TABLEAU 1 (*suite*)

Stratigraphie	*Lithologie* (faciès salifères)	Sels	Répartition géographique	Caractères hydrogéologiques	Concentrations maximums observées des eaux (résidu sec)
Jurassique moyen	Marnes vertes ou rouges gypseuses	Gypse	Bassin de moyenne Moulouya, moyen Atlas, localisé (Taourirt, Immouzer des Marmoucha)	Imperméable	3 à 5 g/l
Lias:					
Domérien	Calcaire gypseux	Gypse	Haut Atlas (Kerdous), très localisé		
Lias inférieur	Anhydrite, sel gemme	ClNa, anhydrite	Sillon sud-atlasique (bassin du Ziz), non affleurant		
Infra-Lias	Dolomie, argiles et marnes gypseuses	Gypse	Très localisé: moyen Atlas et haut Atlas central	Imperméable	
Trias	Argile rouge, gypse et sel gemme massif	ClNa et gypse	Principal terrain salifère. Affleurements: périphérie du moyen Atlas (vallée de l'oued Serrou) et du haut Atlas central (région d'Argana, vallée de l'oued Tessaout). Nombreux affleurements localisés dans le Rif (nappe prérifaine), le haut et le moyen Atlas. Bordure nord-ouest de la Meseta. En outre, forme le substratum du Lias dans tout le domaine atlasique.	Imperméable (les dolérites du Trias, perméables, ne sont pas salifères)	2 à 4 g/l (sources au contact Lias-Trias)
Primaire:					
Viséen	Marnes et gypse	Gypse	Jebel Ouarkziz (sud Anti-Atlas)		
Carbonifère	Schistes et marnes	Chlorures et sulfates	Zones côtières atlantiques (Meseta côtière, Chaouia) et	Nappes phréatiques discontinues (zone d'altération)	5 g/l
Dévonien	(Niveaux pyriteux, alunifères)	Alun, pyrite	domaine anti-atlasique	Imperméable	5 à 20 g/l
Gothlandien		Gypse secondaire			
Acadien					
Géorgien	Marnes gypseuses	Gypse	Localisé dans l'Anti-Atlas occidental (nord-est du LKST); niveaux salifères discontinus		

TABLEAU 2. Composition de quelques types d'eau salée du Maroc (exemples choisis parmi les eaux les plus salées de chaque région)

Type	Origine	Point d'eau	N° d'inventaire du CEH	Teneur en mg/l des principaux ions						D. h.	Résidu sec	Faciès[1]
				Ca^{++}	Mg^{++}	$Na^{+}+K^{+}$	Cl^{-}	SO_4^{--}	$CO_3^{--}+CO_3H^{-}$		mg/l	
Eaux d'oued (étiage moyen)	Oued R'Dat	Débouché Haouz	486/44	108	126	299	600	403	108	79	1 540	C.S.
	Oued Gaïno	Amont El Kelaa des Sharna	58/45	170	1 050	301	763	175	280	130	1 907	
	Oued Sra	Pont de Sker	—	260	63	1 594	2 840	202	102	84	5 248	
	Oued Aoulaï	Rhafsaï	—	200	75	1 171	2 130	154	96	76	4 100	
Eaux d'oued (crues d'automne)	Oued Ziz (13. 9. 56)	Erfoud	680/57	150	128	512	817	572	162	91	2 380	C.S.
	Oued Rhéris (26. 10. 56)	M^ay^ Brahim	1 386/57	243	240	1 047	1 647	1 297	118	159	4 720	
Eaux souterraines en contact avec des terrains salifères (soit l'aquifère, soit le substratum)	Plaine du Rharb:											
	Miocène	Sondage Zrar	482/14	280	142	900	1 761	579	108	120	3 874	C.S.
	Pliocène	Sondage	75/8	116	50	1 212	1 748	315	2 070	52	4 030	
	Chaouia (schistes primaires)	Puits à Bouskoura	25/19	250	197	749	1 732	287	170	143	3 480	C.S.
	Plaines de Berrechid:											
	Contact primaire	Puits	999/27	220	159	1 044	1 892	192	216	129,5	4 144	C.S.
	Contact Trias	Puits	1 600/20	80	136	2 015	3 000	576	192	75	6 160	
	Plaine des Doukkala (plio-quaternaire)	Puits (centre)	1 011/34	328	225	1 099	2 704	187	80	173	4 724	C.S.
		Puits (centre)	134/27	621	240	1 589	2 624	2 074	92	254	7 394	
	Plateau des Phosphates crétacé	Sondage oued Zem	16/29	586	101	20	32	1 650	135	178	2 670	S.C.
	Hauts plateaux, région de Berguent											
	Néogène continental	Sondage oued Za 3	32/18	1 728	956	74 260	115 000	6 700	18	769	215 000	H.C.S.
	Alluvions oued Za	Sondage	17/18	415	229	—	715	1 556	126	141	4 600	S.C.
	Rif (contact Trias)	Source J. Tissa	1 452/15	1 508	605	123 109	191 500	3 950	16	626	319 040	H.C.S.

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[1] C.S. = chloruré sodique; H.C.S. = hyperchloruré sodique; S.C. = sulfaté calcique; B.S. = bicarbonaté sodique; S.S. = sulfaté sodique.

TABLEAU 2 (*suite*)

Type	Origine	Point d'eau	Nº d'inventaire du CEH	Teneur en mg/l des principaux ions						D. h.	Résidu sec	Faciès[1]
				Ca^{++}	Mg^{++}	$Na^{+}+K^{+}$	Cl^{-}	SO_4^{-}	CO_3^{--} $+CO_3H^{-}$			
											mg/l	
Eaux souterraines en contact avec des terrains salifères (*suite*)	Moyen Atlas (contact Trias)	Source Oum er Rebia	147/30	86	39	1 104	1 700	111	160	37,5	3 246	
	Haut Atlas (contact Trias)	Source haut Rheris	41/47	155	58	989	1 633	263	132	47	3 432	C.S.
		Source Amassine	35/45	246	81	421	724	594	138	96	2 240	
	Haut Atlas occidental: pliocène	Puits à Tamanar	23/60	1 260	2 920	3 595	13 210	4 075	—	1 402	27 730	C.S.
	Jurassique supérieur	Sondage L.A. 1	—	575	78	1 018	637	2 028	622	166	5 814	S.C.
	Bassin de Mogador(contactTrias)	Source J. Hadid	48/43	750	400	3 801	7 792	638	93	325	14 000	C.S.
	Sillon sud-atlasique											
	Infra-cénomanien	Source	265/47	765	127	121	284	2 060	82	243	3 460	S.C.
			677/57	136	274	3 550	6 285	795	837	157	13 590	C.S.
	Sénonien	Puits	358/48	589	512	2 055	4 440	1 745	214	398	10 260	C.S.
			296/47	589	174	154	171	2 019	108	219	3 350	S.C.
	Vallée du Dra (quaternaire gypseux)	Puits au Fezzouata	37/73	635	538	1 849	2 833	3 180	310	380	9 420	S.C.
	Plaine du Tafilalet (quaternaire gypseux)	Puits au Tizimi	675/57	550	166	45	335	803	513	193	2 912	S.C.
		Puits au Tizimi	461/57	645	309	1 400	1 570	3 450	79	270	7 490	S.S.
	Anti-Atlas, vallée du Ferkla (quaternaire sur primaire à venues de CO_2)	Puits	328/56	78,5	150	544	377	391	1 030	75	2 000	B.S.
Eaux de nappes phréatiques du Maroc semi-aride en plaines mal drainées (quaternaire ou plio-quaternaire)	Plaine des Triffa	Puits	652/57	352	292	918	2 343	365	238	208	4 580	
	Plaine du Gareb	Puits (sud)	143/6	219	420	3 109	5 432	929	250	227	10 680	
		Puits (centre)	358/6	166	221	2 573	3 960	909	236	132	8 120	
	Plaine du Rharb nappe phréatique	Puits (ouest)	387/8	540	507	1 040	2 600	1 644	210	345	6 500	C.S.
		Puits (sud-est)	160/14	163	144	1 062	1 576	745	188	100	3 996	
	Plaine du Saïs	Puits à Douyet	1 126/15	12	138	764	670	768	312	60	2 500	
	Plaine du Haouz	Puits(nord-ouest)	236/44	188	168	702	1 228	556	226	116	3 160	
	Souss	Puits oued Teima	1 615/70	565	138	364	623	1 534	189	188	3 510	S.C.

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TABLEAU 2 (*suite*)

Type	Origine	Point d'eau	Nº d'inventaire du CEH	Teneur en mg/l des principaux ions						D. h.	Résidu sec	Faciès[1]
				Ca^{++}	Mg^{++}	$Na^{+}+K^{+}$	Cl^{-}	SO_4^{--}	CO_3^{--} $+CO_3H^{-}$			
											mg/l	
Eaux de nappes phréatiques concentrées par évaporation (bassins fermés et régions arides présahariennes) Quaternaire	Plaine du Tafilalet	Puits	261/57	413	834	2 240	4 416	2 676	174	415	10 870	
			1 076/57	392	1 118	2 972	7 000	2 700	300	560	14 500	
			1 324/57	720	1 876	4 989	9 420	6 600	192	882	24 288	C.S.
			1 450/57	810	3 200	13 846	23 572	11 328	124	1 450	53 136	
	Basse vallée de l'oued Ziz	Puits à Remlia	71/66	720	2 744	12 218	18 886	11 725	212	1 308	48 190	
			72/56	812	3 404	14 266	24 069	11 775	198	1 602	57 910	H.C.S.
			51/66	750	3 875	17 542	29 300	13 201	218	1 778	67 084	
	Vallée moyenne du Dra	Puits au M'Hamid	110/82	708	470	909	2 800	1 175	290	369	720	
		Puits du Ktaoua	64/82	640	1 248	2 212	7 100	1 305	150	715	12 600	
			44/82	548	1 686	2 794	8 900	1 651	150	830	15 800	C.S.
Eaux de nappes phréatiques concentrées par évaporation (bassins fermés et régions arides présahariennes)	Basse vallée de l'oued Dra	Forage	11/92	970	2 615	11 921	20 600	8 759	100	328	45 800	C.S.
		Source oued Tissint	66/81	228	240	2 850	3 365	268	144	168	6 378	
	Oued Zennoul	Forage Hasi el Mounir	14/94	732	57	6 831	12 020	15	132	229	20 676	
	Oued Noun	Puits	104/88	279	571	1 786	2 840	2 592	138	305	8 310	C.S.
	Région de Tarfaïa	Puits	T. 14	282	372	2 586	4 560	1 056	120	223	9 248	
Eaux de nappes phréatiques côtières contaminées par invasion d'eau de mer (plio-quaternaire)	Zone de Saïdia	Puits	1 002/7	25	95	1 609	2 272	565	100	45	4 680	
	Région de Nador	Sondage	1 005/7	93	904	9 154	16 230	466	304	395	27 520	
		Puits	215/6	928	586	3 148	6 426	1 830	188	473	13 580	
	Zone côtière Rharb	Sondage M.C. 1 (— 170 m)	158/8	802	1 258	10 114	18 673	2 569	260	668	35 360	
	Zone côtière Rabat	Puits	529/13	102	228	1 136	2 028	287	150	121	3 950	C.S.
	Zone Casablanca	Puits	1 364/19	1 190	450	1 393	4 976	461	96	482	8 804	et
	Zone Mazagan	Piézomètre	1 209/19	724	1 312	11 718	20 448	3 502	110	720	38 262	H.C.S.
	Embouchure oued Tensift	Source	25/43	389	1 043	8 118	14 624	2 117	99	648	28 020	
	Zone sud de Safi	Puits	261/34	187	328	2 720	4 687	960	99	169	9 050	

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TABLEAU 2 (*suite*)

Type	Origine	Point d'eau	N° d'inventaire du CEH	Teneur en mg/l des principaux ions						D. h.	Résidu sec	Faciès[1]
				Ca++	Mg++	Na++K+	Cl⁻	SO₄⁻⁻	CO₃⁻⁻ +CO₃H⁻		mg/l	
Eaux "connées" associées à des gisements d'hydrocarbures[2]	Haricha pré-Rif (jurassique moyen)	Sondage H.R. 2		4 973	1 160	42 222	77 022	118	329	1 608	129 010	C.S.
	Bou Dra pré-Rif (Lias)	Sondage B.D. 133		4 141	1 137	28 310	49 374	2 728	622	1 405	89 664	C.S.
	Région d'Essaouira (Lias)	Sondage K.E. 1		76 250	17 450	37 989	244 286	113	122	24 550	434 120	

1. C.S. = chloruré sodique; H.C.S. = hyperchloruré sodique; S.C. = sulfaté calcique; B.S. = bicarbonaté sodique; S.S. = sulfaté sodique.
2. Renseignements communiqués par la Société chérifienne des pétroles.

sud-est (cf. fig. 3): ce sont des lacs salés temporaires, mais dont le fond demeure toujours humide, où l'eau s'évapore durant la saison sèche.

Les sebkhas n'existent pas seulement dans les bassins fermés, mais dans tous les bassins hydrologiquement dégradés, où elles sont l'aboutissement de cours d'eau impuissants à affluer à l'artère principale. Leur eau n'est pas toujours salée, mais peut être relativement douce au moment de leur remplissage (1 à 2 g/l). Certains sont au-dessous du niveau de la mer, telle la sebkha Tah, près de Tarfaya (— 50 m).

Un cas particulier est celui de la sebkha Zima, dont l'impluvium s'étend largement sur du trias salifère et où le sel est exploité: son eau peut atteindre une teneur de plusieurs centaines de g/l.

Les merja, enfin, sont des lagons fréquents sur le littoral atlantique, notamment sur la côte du Rharb, dont les eaux sont plus ou moins salées par communication avec la mer.

Sources et eaux souterraines salées

Les eaux salées localisées sont toujours étroitement associées à des terrains salifères dont on a vu la grande dispersion au Maroc. Il s'agit souvent du mur ou du toit imperméable d'un niveau aquifère dont en général l'eau n'est pas salée: par exemple, les eaux du lias souvent, mais très localement, salées par le trias.

De tels points d'eau salée se rencontrent donc dans presque toutes les régions du Maroc, sans relation directe avec l'intensité de l'aridité.

En règle générale, la salure des eaux de sources est inférieure à celle de la nappe qui les alimente et inversement proportionnelle à leur débit. Cependant la source la plus importante du Maroc, celle de l'Oum er Rebia (plusieurs m³/s), est salée (3 g/l). C'est dans ce type d'eau salée que se rencontrent les plus fortes concentrations connues: eaux en contact avec du sel gemme massif, ou eaux "connées".

Les régions où les eaux salées prennent une certaine extension au point que les eaux douces sont rares ou absentes, sont: *a*) celles où les principaux niveaux aquifères sont salifères dans leur masse, et non pas seulement le substratum; c'est le cas d'une grande partie des Abda, région de Safi (jurassique), d'une partie de la cuvette de Berguent (néogène) de la nappe du cénomanien du plateau des Phosphates; *b*) celles où prédominent des terrains peu perméables et où le drainage s'effectue mal: massifs anciens schisteux du nord-ouest, certaines plaines du Maroc atlantique (Rharb, Chaouia, Doukkala) ou du Maroc oriental (Triffa); *c*) celles où les eaux souterraines sont soumises à l'évapotranspiration: nappes phréatiques peu profondes de tout le domaine présaharien et de la plupart des bassins fermés (Bahira, chotts du sud-est).

Fréquence des concentrations. Dans les régions où prédomine la concentration par dissolution les eaux titrent rarement plus de 10 g/l et le plus souvent, moins de 5 g/l;

les eaux titrant de 2 à 5 g/l sont les plus fréquentes. En revanche dans les régions où prédomine la concentration par évaporation, se trouvent les eaux salées étendues les plus concentrées: les maximums locaux dépassent presque toujours 10 g/l et souvent 20 g/l. Le maximum connu est de 67 g/l (vallée du Ziz).

Toponymie. La présence d'eaux ou de terrains salés se signale souvent dans la toponymie marocaine: beaucoup de noms de lieux, de sources ou de cours d'eau signifient "salé", par exemple les nombreux oueds Mellah et les noms berbères forgés sur les racines "iss" (Tissa, Issen, Tissint), Amassine ou Temassint, ou "marhar" (Tamarhart, Imarhiren, Marha).

En conclusion, on soulignera deux faits:

a) L'extension qualitative des eaux salées au Maroc importe plus que leur débit: s'il n'est pas possible, en l'état actuel des connaissances, de chiffrer la proportion d'eaux salées pour l'ensemble des ressources en eau du pays (qui sont de l'ordre de 15 milliards de m^3/an[1]), il est certain qu'elle est globalement faible, et vraisemblablement inférieure à 10%, mais elle doit être plus élevée pour certaines régions considérées isolément.

A peu d'exceptions près, les sources et nappes d'eau salée ont en effet de faibles débits et les oueds salés ne totalisent qu'une petite part du débit global des eaux superficielles.

b) Dans la plupart des bassins du Maroc, l'éventail des concentrations des eaux est largement ouvert. Si les eaux salées sont très répandues, il existe fort peu de régions entièrement dépourvues d'eau douce, au moins localisée. En outre, le débit de celles-ci est en général proportionnellement plus important que leur extension.

COMMENT SE FORMENT LES EAUX SALÉES AU MAROC: LES MÉCANISMES DE CONCENTRATION

La concentration des eaux en sels résulte pour l'essentiel, on l'a vu, de deux processus parfois combinés, mais distincts, dont on examinera l'importance respective au Maroc.

Concentration par dissolution

Le facteur principal est la teneur des terrains en sels, mais la salinité de l'eau n'est pas proportionnelle à celle du terrain. La distinction entre les terrains réputés salifères et les autres est en effet purement quantitative. La concentration étant fonction non seulement de la salinité du terrain aquifère, mais de sa porosité et de la vitesse d'écoulement des eaux souterraines (elle-même fonction du gradient hydraulique), les eaux peuvent atteindre des concentrations élevées dans des terrains très peu salifères comme certains schistes ou marnes et les alluvions argileuses, ou dans des bassins fermés, où la mise en équilibre chimique de l'eau et de l'aquifère n'est pas limitée par le temps.

C'est ainsi qu'au Maroc, à côté des eaux salées en contact avec des terrains salifères indiscutables, les eaux sont salées aussi dans la plupart des terrains schisteux et marneux et les roches éruptives altérées, même dans les régions relativement humides (Meseta côtière et massif central: eau à 2 à 5 g/l), ainsi que dans les plaines d'alluvions fines à nappe phréatique quasi stagnante, où l'effet de l'évaporation peut d'ailleurs s'ajouter (Rharb: eau à 3 à 6 g/l).

Enfin, la température relativement élevée des eaux souterraines est un facteur non négligeable: dans plus de la moitié du pays, les eaux phréatiques ont une température de 18 à 20° pendant plus de six mois.

Concentration sous l'effet de l'évapotranspiration

Elle se produit suivant des processus plus ou moins complexes, soit isolément, soit en combinaison avec la concentration par dissolution.

Le cas le plus simple est celui de la concentration d'eau superficielle, dans les bassins fermés: ce sont les sebkhas, déjà citées.

Le processus de concentration des eaux souterraines est fonction à la fois du régime de l'évapotranspiration et du régime des fluctuations des nappes phréatiques dont les effets se combinent différemment suivant les régions et les saisons.

La mise en équilibre chimique de l'eau et du terrain s'effectue dès qu'une concentration de l'ordre de 3 à 5 g/l est atteinte. Il se produit ensuite une concentration commune de l'eau et du terrain, les sels moins solubles (gypse) se déposant surtout dans le terrain aquifère et ClNa formant une croûte superficielle par évaporation totale de l'eau remontée par capillarité.

Dans le cas des nappes phréatiques alimentées principalement par infiltration d'eaux superficielles (palmeraies présahariennes irriguées par épandage d'eau de crue, plaines inondables, dites "maider"), la concentration est la résultante d'un lessivage périodique des croûtes salines, formées, en saison sèche, par l'eau infiltrée.

L'écoulement, même très lent, de ces nappes entraîne un maximum de concentration à l'aval des zones d'alimentation. Suivant l'intensité et la durée des épandages et la perméabilité de l'aquifère, on observe un accroissement de salinité de l'eau ou au contraire une dilution lorsque les nappes sont rechargées. Enfin, une vague de salinité annuelle, se propageant beaucoup plus lentement que l'onde de transmission de charge, a été observée à l'aval de certains de ces périmètres.

La plus grande fréquence des processus de concentration sous l'effet de l'évaporation dans la genèse des principales étendues d'eau salée au Maroc souligne ainsi le rôle fondamental de l'aridité du climat.

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[1] Ressources potentielles, dont 25% sont utilisées.

SUMMARY

Salt waters in Morocco (J. Margat)

General study of the salinity problem in Morocco. Present state of knowledge. After a description of the general climatic, hydrological and geological conditions, the main question dealt with is that of the salinity of underground waters: composition, geochemical facies, distribution and origin of salt waters. The prime factor in determining the salinity of water is concentration by evaporation—an effect of aridity. Practical problems arising; research planned.

DISCUSSION

G. **Drouhin.** M. Ambroggi, parlant au nom de M. Margat, a signalé les tentatives faites pour "décontaminer" des nappes côtières envahies par l'eau de mer. Serait-il possible d'avoir une idée des procédés techniques que l'on compte mettre en œuvre à cet effet?

R. **Ambroggi.** (1). Expérience de Tanger: la nappe utilisée pour l'alimentation en eau de la ville a baissé de 20 m en cinq ans et se situe maintenant à — 4 m; la salinité, à l'origine égale à 400 mmg/l, est passée en certains points à 4 g/l; une solution d'urgence a consisté à injecter dans la zone d'alimentation 15000 m^3/j d'eau douce alors que l'exploitation n'est que de 10000 m^3/j; le supplément ainsi apporté a stoppé le début d'invasion marine.

(2). Nos projets: sur les nappes côtières contaminées, *a*) créer en bordure de la mer un rideau à sondages d'injection d'eau douce pour dresser un véritable "mur" d'eau douce entre la mer et la zone contaminée; *b*) dans le même temps creuser dans les zones d'alimentation des bacs d'absorption pour y injecter de l'eau douce en quantité suffisante pour restaurer la nappe.

SOIL SALINITY IN NON-IRRIGATED ARABLE AND PASTORAL LAND AS THE RESULT OF UNBALANCE OF THE HYDROLOGIC CYCLE

by

R. G. DOWNES

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INTRODUCTION

Although saline soils occur naturally in many arid and semi-arid parts of the world, they frequently occur as the result of man's use of the land, particularly under irrigation. In Australia, excessive soil salinity is becoming more common in certain kinds of non-irrigated arable and pastoral land in both semi-arid and sub-humid regions. These occurrences are considered to be due to changes in the hydrologic regime following man's alteration of the ecosystems and subsequent use of the land during a period of nearly 80 years.

THE NATURE OF THE HYDROLOGIC CYCLE

In a catchment area the hydrologic balance can be expressed in the form of the following equation:

$$P = E + T + R + I \qquad (1)$$

where P = precipitation, E = evaporation, T = transpiration, R = surface run-off, and I = soil moisture increment.

When the amount of precipitation is only just sufficient, or is less than sufficient, to meet the requirements of the potential evapotranspiration, then the values for R and I are insignificant and

$$P = E + T \qquad (2)$$

Under these conditions the value for T is limited by the amount of soil moisture available for absorption and transpiration within the root zone of the vegetation. Consequently, any alteration in the infiltration capacity of the soil, or in the type of vegetation and the volume of soil being exploited by plant roots, or in the transpiring capacity of the vegetation because of either less plants per unit area, or because of constant defoliation, will change the amount of water being transpired (T).

Changes in soil structure and infiltration capacity often accompany the vegetational changes imposed by man and these can affect, for better or for worse, the amount of water entering the soil and becoming available in the root zone.

The most common changes in catchments in which the values for R and I are normally insignificant, are those which tend to lead to lower values for T; the changed moisture status of the system is then reflected by significant values for R and I.

This situation can be expressed by

$$P = E + Tc + Rc + Ic \qquad (3)$$

where Tc, Rc, and Ic represent values of the relevant components for the changed conditions.

If under natural conditions the vegetation consisted of deep-rooted tree species, a forest or scrub formation, and the transpiration was T_1, then

$$P = E + T_1 \qquad (4)$$

But if the vegetation is changed to grazed perennial grasses having a transpiration T_2, or to shallow-rooted annual pastures having a transpiration T_3, or to an overgrazed or overcleared sparse open vegetative cover having a high percentage of bare ground and a transpiration T_4, then the situations are expressed by the following equations

$$P = E + T_2 + R_2 + I_2 \qquad (5)$$
$$P = E + T_3 + R_3 + I_3 \qquad (6)$$
$$P = E + T_4 + R_4 + I_4 \qquad (7)$$

There is no doubt that there would be small consequent changes of the values of E because of the changed ability of the vegetation to intercept and hold on its surface precipitation which can be evaporated. However, these different values for E, which generally would tend to decrease as the amount of vegetative cover decreased, can be neglected for the purpose of this discussion.

For the conditions stated above $T_1 > T_2 > T_3 > T_4$, and consequently $(R_2 + I_2) < (R_3 + I_3) < (R_4 + I_4)$. Thus changes in vegetative type, which lead to progressive reductions in the moisture transpired, provide increasing amounts of unused water in the system. Whether this increased water causes an increase in the value of R or I, or both simultaneously, depends on other characteristics of the catchment, such as the ability of the vegetative cover to hold water on the surface of the soil, the infiltration capacity of the soil, the moisture-holding capacity of the soil, the presence or absence of horizons of low permeability in the subsoils, the slope of the land, the seasonal distribution and intensity of the rains, and the amount by which potential evapotranspiration exceeded the actual value in the system in its natural state.

The ways in which these factors will operate to favour increases in either R or I are almost self-evident.

Increases in R and I need not necessarily cause trouble so long as they are anticipated and appropriate safeguards are taken to protect the system from their possible ill effects. In fact, with careful management the increased water can be beneficial. An increase of R can produce a useful increased water yield from a catchment, provided its rate of movement can be controlled to prevent erosion, and it can be conserved for more useful purposes; uncontrolled it may lead to soil erosion and a generally more arid environment. An increase in I can provide additional soil moisture for growing at suitable intervals more valuable crops with a higher water requirement, but it can also cause loss of water from the system by deep percolation, or increased seepage and local waterlogging in lower parts of the catchment.

The soil moisture increment (I)—the water in excess of transpiration—can be disposed of in three ways, which are expressed by

$$I = U + S + A \qquad (8)$$

where U = underground loss by deep percolation, S = seepage or laterally moving moisture, and A = the increment to the possible soil moisture storage. It is obvious that A must usually be satisfied before either U or S have significant values.

U will only attain appreciable values in catchments where the changes of T are sufficient to mean that P greatly exceeds the value of E + T, and when the soils and parent materials are readily permeable to considerable depth. It can be significant in irrigation areas where P itself is increased greatly, but in non-irrigated areas, where the potential evapotranspiration originally equalled or exceeded the precipitation, the value for U is almost negligible.

The increased value of I is mainly disposed of by an increase of A. However, in catchments where the precipitation is equal to or only a little less than the evapotranspiration, or where the soils have a low field capacity, or where there is a relatively impermeable subsoil at shallow depth, A quickly reaches its maximum value and S will attain a significant value.

It is proposed now to show that the increasing salinity in non-irrigated arable and pastoral land in Australia has been due to reductions in values for T because of the changes in the character of the vegetation, and this has caused consequent changes of I which have been disposed of in increased values for A and S. The increased seepage has enabled the redistribution and concentration of salt in certain topographical locations.

SOIL SALINITY IN NON-IRRIGATED AREAS IN SOUTHERN AUSTRALIA

Increasing salinity in non-irrigated areas was first noticed about 50 years ago in parts of Western Australia used for wheat growing. Since then its incidence and severity have increased, and it is now a serious problem. Teakle [14][1], Burvill [2] and Pennefather [12] have reviewed the problem and it is clear that salting has occurred only after extensive clearing of the land and its subsequent use for wheat growing. The most common and most extensive occurrences of salting are in the broad valleys in gently rolling semi-arid country having an average annual rainfall of 11–15 in. The soils in these areas are naturally saline and the salting results from a redistribution of the salt and its concentration in the surface horizons of the soils at lower levels.

Although by no means as extensive, salting has also occurred in the wheat-growing areas of north-western Victoria, where the soils also have some natural salinity and the average annual rainfall is between 12 and 14 in. These occurrences are similarly found in lower parts of areas which have been cleared and used for wheat growing.

However, the major problem of salting on non-irrigated land in Victoria arises in particular kindsof country in which the soils are not naturally saline and where the average annual rainfall may be 20–30 in. In these areas of rolling or hilly country, which have been mainly used for grazing following clearing of the dry sclerophyll forest, there is an increasing incidence of salting at the base of slopes and along the drainage lines. The salt-affected parts may vary in size from patches of only a few square yards to areas of nearly 100 acres.

We can therefore say that the two kinds of areas in which salting in non-irrigated land occurs in Southern Australia are (a) semi-arid areas in which there is some natural soil salinity; (b) sub-humid areas in which the soils are not naturally saline. Salting is not universal in areas conforming to these broad conditions, because its occurrence is also related to particular soil and topographical conditions and to the history of land use.

Because of the increasing incidence of salting in Victoria, the Soil Conservation Authority in 1952 initiated investigations. These were mainly directed at the problem of salting in the sub-humid areas, and were concerned with determining the incidence and extent, the causes and possible correction of the problem. In addition, there were investigations into the origin of the salt and the nature of the hydrologic cycle in country typical of that in which the problem occurs. Although by no means complete, sufficient information has already been

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[1] The figures in brackets refer to the bibliography on page 110.

obtained from these investigations to provide some confirmation of an hypothesis concerning the processes operating to produce salting.

THE ORIGIN OF THE SALT

Salt of oceanic origin is being deposited by rain in Southern Australia, the amount in any place depending on the nature and amount of rain, the distance from the coast and local orographic conditions. The evidence for this has been provided and discussed by Jack [10], Prescott [13], Teakle [14] and Anderson [1].

On the basis of this work it is generally considered that the salt in the soils in the semi-arid and arid areas is the result of accumulations of small annual amounts brought in by rain over a long period during recent geological time. In recent work Hutton and Leslie [9] have shown that the salt content of rain-water shows a rapid decrease with increasing distance from the coast. They also claim that in more arid areas it is almost impossible to determine the new accessions of salt because some of the salt in the rain-water is almost certainly of local terrestrial origin. However, Cope [3] quotes the work of Twomey (1955) in which it has been shown that in samples taken from the air-streams of prevailing south-westerly winds blowing across the south-eastern part of the continent, including those over semi-arid areas, there is a small but almost uniform content of salt nuclei (at altitudes of 3,000–3,500 ft.), which must almost certainly be of oceanic origin. It seems, therefore, that small amounts of salt are being brought in by the prevailing winds, and may be flushed from the air and deposited with the rain.

However, the greatest accessions of salt occur near the coast and are the result of low level winds. Hutton and Leslie [9] have shown for stations having more than 25 in. of rain per annum that the amount of salt brought in by rain reaches a relatively low level at about 100 miles inland and beyond.

From these investigations it seems reasonable to believe that in the semi-arid areas the salts (mainly sodium chloride) that are already in the soils and are being redistributed to cause excessive salinity are of oceanic origin. Although small accessions are still occurring, most of the salt is the result of accumulation over a long period of time.

It also seems that the salt which is causing trouble in the sub-humid areas can only be of oceanic origin and brought in with the rain. In Victoria, areas having a rainfall of 20–30 in. may receive anything from 8 to 30 lb. of sodium chloride per acre per annum from the rain, but in areas within 50 miles of the coast the amounts can be 60–100 lb. of sodium chloride per acre per annum.

THE NATURE OF THE ENVIRONMENTS

The nature of the environments in which salting occurs in Victoria and the problems of management resulting from their occupation and use by man have been described by Cope [3, 4] and Downes [7, 8]. Broadly the characteristics are these:

The semi-arid environment (12–14 in. rainfall). The topography consists of east-west sand-dune ridges superimposed on a gently undulating plain. The vegetation consisted of a Eucalyptus spp. scrub locally known as Mallee. The soils are generally light textured, frequently being deep sands on the ridges, but on the interdune corridors they have a slightly heavier texture which gradually increases with depth. There is no regional drainage pattern, an indication that potential evapotranspiration exceeded the precipitation and that consequently $P = E + T$, the value of T being limited by the available moisture in the root zone. From exposure on eroded dunes it can be seen that the Mallee scrub has a root system which exploits widely and deeply. The light-textured soils readily absorb water, but they have a low field-capacity and consequently the environment is arid for shallow-rooted annuals but satisfactory for the deep-rooted scrub which in dry times can make use of water in the deep subsoil.

The area was cleared for wheat, which can be successfully grown after a year of bare fallow to increase moisture storage. Under cultivation, the sand dunes became unstable and were soon unsatisfactory for wheat growing; they were therefore left bare.

The changed hydrologic system resulting from clearing and use can be expressed by $P = E + Tc + Rc + Ic$, in which Tc is less than the original T, Rc is almost zero because of the nature of the soils and Ic attains an appreciable value. The increase of Ic is disposed of mainly in the form of an increase in A in the deep subsoil, where ultimately a water table is established and S attains a positive value; there is then lateral seepage.

The water table comes close to the surface on the lower slopes of the dunes and in the nearby interdune area. Evaporation at the surface concentrates salt which is brought up from the saline subsoils of the interdune areas, together with any additional salt which has been flushed from the dune areas by leaching. Although the salt content of the dune soils is not particularly high, there is a large volume from which salt can be removed and concentrated in relatively small areas. Even without the addition of this salt trouble could arise, because the interdune soils commonly have a content of about 0.1 per cent at a relatively shallow depth.

The sub-humid environment (20–30 in. rainfall). The topography is rolling to hilly and the soils are solodic, showing a sharp transition from medium-textured A_1 and A_2 horizons to a heavy clay B horizon. The origin of these soils is said by Downes [7] to be accumulation of oceanic salt in the Recent Arid period, and subsequent desalinization. The vegetation was originally a dry sclerophyll forest of *Eucalyptus* spp. About 80 years ago these areas were extensively cleared to enable the native perennial grasses, *Danthonia* and *Stipa* spp., to form a sward which was grazed mainly by sheep. Recently, large areas have been sown to improved annual pastures, mainly subterranean clover (*T. subterranean*), by using molybdenum in addition to superphosphate. Some areas of native pastures have been seriously overgrazed, leaving a poor vegetative cover of unhealthy perennial grasses and a few small shrubs. In these latter circumstances much erosion has resulted from the increased run-off. The surface soils have a naturally poor structure which is easily damaged when the vegetative cover is reduced, but under good pasture of either native perennials or improved annual species the infiltration capacity is maintained. Under the influence of subterranean clover it is improved. Leslie [11] has shown that after a few years of clover the infiltration capacity is about twice that under native grasses.

The changing hydrologic conditions in this environment are expressed by the equations 4, 5, 6 and 7. The situation expressed by equation 7 is not relevant to this discussion, because the surface soils become impermeable and the increase of $(R_4 + I_4)$ is mainly due to an increase of R, which causes the erosion troubles previously discussed by Downes [5, 7, 8]. The relevant equations are 5 and 6, in which the increased $R + I$ is almost entirely disposed of in I, and since there is an horizon of low permeability about 12 in. below the surface, A soon reaches a maximum and most of the increase is shown in S. This increased seepage causes waterlogging of the surface soil at the base of slopes and along the drainage lines.

In these areas, about 25 lb. of NaCl per acre is brought in by the rains each year. This represents an increment of 5 ppm. to the top 12 in. of soil. Under natural conditions this salt was absorbed and stabilized in the vegetation, or even to some extent in the surface soils of the catchment. Cope [3] has found that the surface soils of undisturbed forested catchments may contain about 0.04 per cent NaCl, an amount which could be accumulated in the relatively short period of 80 years if no salt were being lost from the system. From this it may be inferred that either the vegetation itself has absorbed and holds large quantities of salt, or that there is a periodical flushing of salt from the system in years with above-average rainfall.

With the increased seepage following the changed vegetative conditions, both the salt held in the catchments and the salt coming into the catchments with the rain are carried down to lower levels. Even so, the salt concentration in the seepage water is not high enough to cause trouble provided vegetation is maintained in the seepage areas. But because they are wetter sites, the pasture thereon maintains growth and remains green later in the season; and because of their slight salinity, this same pasture is most attractive to stock and the areas are inevitably eaten bare. Without vegetation to use the water and absorb the salt there is evaporation from the surface, the salt remains in the soil and year by year the small accumulations build up to toxic concentrations.

If all of the salt in the surface soils of undisturbed catchments is concentrated into an area of $^1/_{10}$ of the total as a result of the disturbed hydrologic conditions, then a significant content of 0.4 per cent can be attained in the seepage areas.

However, the continual accession of salt from the rain can also make a significant contribution, because a similar concentration of 0.4 per cent could be attained in a period of 80 years by movement and accumulation in an area of $^1/_{10}$ of the catchment following disturbance of the hydrologic balance.

Together the salt from both sources could provide an accumulation of 0.8 per cent NaCl in areas of $^1/_{10}$ of the catchment size.

Observation shows that no salting occurs in catchments which are still forested; there is some salting in catchments having good perennial grass cover, but salting is now appearing in catchments having improved annual pasture cover. This is a fairly recent form of land-use, and it is difficult to decide whether the increase of salting in these areas is a result of the changed vegetative cover having a significantly shallower root system, or of the run of wetter than normal seasons which was concurrent with much of this pasture improvement. This situation may be clarified after the completion of hydrological experiments which are now in progress.

CONCLUSION

From studies on salting in non-irrigated arable and pastoral land in Victoria it is clear that in some areas where there is salt already in the soils or where salt is being brought in by rain, man's use of the land has altered the system in a way that enables a redistribution and concentration of the salt in particular parts of the system. The changes to the system that bring about salting are alterations to the type of vegetation and consequently to its root characteristics and water-using capacity. The reduction in transpiration allows excess water to accumulate in the system, which ultimately leads to seepage and the movement and subsequent concentration of salt in toxic amounts in small areas.

The major point of interest in these phenomena is that in environments where normally $P = E + T$, changes of vegetative type which tend to reduce the value of T will result in significant amounts of excess water in the system, and provision must be made for its use or safeguards provided against its possible ill effects. Consequently in such environments the forms of land-use most likely to be successful and least likely to cause trouble are those in which a higher level of production can be obtained by different species of the same vegetative type or by species having a similar water requirement and able to make use of water from a similar volume of the soil.

In the semi-arid areas the problem is being overcome by much more extensive use of lucerne on the sandy rises. Having a deep root system and being a perennial species, it is able to make use of water escaping to the deep subsoils. In the sub-humid areas annual improved pastures will probably not succeed in stabilizing the hydrologic regime and may even aggravate the problem by comparison with the perennial native pastures. Although the annual pastures have a high water requirement in the spring they are shallow-rooted and do not dry out the deeper soil horizons during the summer. Consequently, to re-establish a hydrologic balance it will be necessary to introduce deeper-rooting perennial grasses and perhaps even a certain number of trees to ensure proper water use on the catchment and elimination of seepage.

Although this outline of the problem, its probable causes and means of correction appear logically sound, investigations are proceeding to obtain more conclusive data.

ACKNOWLEDGEMENTS

In addition to quoted references, some of the statements made in this paper are based on preliminary evidence furnished by investigations now being carried out by officers of the Research Division of the Soil Conservation of Victoria.

RÉSUMÉ

Influence d'un déséquilibre du cycle hydrologique sur la salinité des champs et pâturages non irrigués

(R. G. Downes)

Dans les aires d'alimentation où l'évapotranspiration potentielle est plus forte que les précipitations, toute modification de la nature de la végétation entraînant une réduction des quantités d'eau perdues par transpiration provoquera une modification du bilan hydrologique. Quand le sol sera saturé, l'eau en excès s'infiltrera vers les couches profondes.

Lorsque la terre contient des sels ou que la pluie lui en apporte, ces sels entraînés par l'eau d'infiltration peuvent s'accumuler au point de dépasser en certains endroits le seuil de toxicité, provoquant ainsi la dégradation du sol et une diminution de sa fertilité.

Les observations faites à cet égard dans diverses régions de l'Australie montrent qu'on ne saurait organiser l'exploitation du sol sur une base permanente dans de telles aires d'alimentation sans rétablir d'abord l'équilibre hydrologique. A cet effet, il est indispensable d'y faire pousser des plantes ayant des caractéristiques radiculaires et une capacité d'utilisation de l'eau aussi semblables que possible à celles de la végétation originelle.

DISCUSSION

M. L. DEWAN. (1) What are the infiltration rates on soils of semi-arid (including interdune) areas and subhumid environments?

(2) What remarks would the author care to make on the need for fallow in areas where dry farming is practised, especially in view of salinization, which is sometimes a consequence of fallow?

G. DOWNES. (1) I am unable to give you specific data for these infiltration rates. In the semi-arid region under discussion the rates are high because the soil textures are sandy. In the interdune areas the texture does rise, but only gradually, to about a sandy clay loam. In the sub-humid areas the infiltration rates are generally low but the growth of subterranean clover can improve them by 100 per cent after 3 years. Data is available and could be obtained.

(2) Fallowing in the interdune areas is essential for growing a cereal crop, both for water storage and also for the build-up of nitrogen. Fallowing on the interdune areas would not alone have caused salting in these areas. The salting is largely the result of the complete absence of vegetation on the dunes, which become unstable after constant cultivation.

K. AHMAD. I have listened with great interest to Dr. Downes's most able paper. The conditions in some parts of my country are quite analogous. May I inquire what is the most profitable use of land in the inter-sand-dune areas he has mentioned?

G. DOWNES. Although previously these areas were used on a fallow-wheat or fallow-wheat-oats rotation (i.e. continuous cultivation), the present trend is to lengthen the rotations to fallow-wheat-oats followed by 3 to 4 years under pasture, the legume constituent being Barrel Medic. The pastures are used for grazing by sheep, mainly fat lambs because the area is suited to the production of early high-quality spring fat lambs. This method of land-use leads to better yields and a higher quality of cereals and also eliminates the problem of wind erosion, which was formerly widespread.

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HYDROLOGIC ASPECTS OF THE SALT PROBLEM IN AGRICULTURE AND ITS CONTROL THROUGH IMPROVED WATER MANAGEMENT IN ARID AND SEMI-ARID REGIONS (WITH PARTICULAR REFERENCE TO PROBLEMS IN INDIA)

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The problem of salinity and alkalinity is fairly widespread in India. Quite a large number of arid and semi-arid areas in Bihar, Uttar Pradesh, Punjab, Rajasthan and Bombay give rise to saline and alkali efflorescences which are locally known under various names, such as *reh, kallar, thur* and *usar.* The Punjab alone may have 3 million acres of such land. Soil survey reports from Uttar Pradesh indicate an area of at least two million acres under *reh* and *usar.*

ANALYSIS OF THE SALT PROBLEM IN INDIA: RESULTS OBTAINED

In 1876 the Government of India set up the Reh Commission to investigate the causes of land deterioration in the Aligarh District (U.P.). According to the report of the commission, *reh* is formed by highly soluble sodium salts which are brought to the surface by capillary action and soil evaporation. The accumulation of salts is accelerated where the water level is near the surface, and the commission found that the introduction of canal irrigation water was the principal cause of *reh.* It recommended the deepening of canals to lower the water table, restricting the use of water to prevent over-irrigation, and deep drainage to remove the surplus subsoil water and the *reh* salts.

According to Auden, Gupta and others who have also investigated *reh* salts in Uttar Pradesh, the principal factors in the formation of salts are: (a) alternating dry and wet seasons; (b) low gradients with slopes less than 5 ft. per mile; (c) high water table; (d) rocks rich in soda mineral; (e) the quality of ground and canal water; (f) base-exchange reaction.

The salt problem made its first appearance in the Punjab around 1850 in the tract irrigated by the Western Yamuna Canal. By 1907, the evil had spread to several other canal systems of the integrated Punjab (prior to the partition of India and Pakistan).

The measures taken at that time to counter the problem comprised the construction of new drains and the re-conditioning of old ones; this led to much improvement. Detailed investigations carried out since then in the Punjab bring out the following important points:

1. Salt that causes salinization is mostly inherent in the soil strata—very little of it is brought by the irrigation water or contributed by the subsoil water table.
2. Prior to the introduction of irrigation, salt is distributed throughout the depth of the soil crust. With the introduction of irrigation, the redistribution of salt takes place, which results in the formation of a zone of accumulation. The zone moves up and down in accordance with the movement of the water.
3. If the upward capillary movement can influence evaporation and the quantity of irrigation water used is insufficient to balance the loss due to transpiration and evaporation, then the zone of accumulation will have a tendency to move upward and cause salinization.
4. If the irrigation water is of sufficient quantity to leach the salt down to a depth from which capillary movements cannot influence evaporation, then the zone of accumulation will remain harmless in the subsoil, below the root zone.

Thus, two important conclusions are deduced: (a) irrigation can cause unfavourable redistribution of salts, even though salinity of irrigation water or a high water table may not be involved; and (b) the cultivation of crops requiring high irrigation, such as paddy, may help the leaching down of salts in areas where the water table is low.

Recently, in the post-partitioned Punjab, the action committee appointed to report on the growing salt menace has emphasized the necessity of improving drainage, lining canal distribution systems to prevent seepage, and encouraging the construction of tube-wells and percolation wells in the affected areas. In order to stabilize the subsoil water table, emphasis has also been laid on the need to prevent the affected areas from being flooded by rivers, big streams and creeks.

Investigation of the salt problem in the Bombay State has also revealed that the deterioration of soil in canal-irrigated areas was related to the existence of the canals and the rising of the water table as a result of irrigation and inadequate drainage. It was found that land could be prevented from deterioration by deepening the *nullahs* and opening feeder drains.

CONTROL OF SALINITY AND ALKALINITY THROUGH IMPROVED WATER MANAGEMENT

It will be obvious from the foregoing discussion that irrigation, leaching and drainage are basic and inter-related elements in any salt problem. Experience in India amply bears out this fact. The inter-relationship may be categorized with reference to two factors: (a) the salt balance in the root zone in relation to the salt-tolerance of the crop; and (b) the stabilization of the water table at a proper level.

Correlation between the water required (for irrigation, leaching and drainage) and the salt balance is expressed by the equations:

$$\frac{D_{dw}}{D_{iw}} = \frac{C_{iw}}{C_{dw}} = \frac{EC_{iw}}{EC_{dw}} \qquad (1)$$

$$D_{iw} = D_{cw}\, D_{dw} \qquad (2)$$

where D_{iw}, D_{dw} and D_{cw} are the volumes per unit area of the equivalent depths of the irrigation water, drainage water and consumptive water respectively; C_{iw} and C_{dw} are the salt concentrations of the irrigation and drainage waters; EC_{iw} and EC_{dw} are the corresponding electrical conductivities of these waters. For all practical purposes the salt concentration of the drainage water represents the concentration of the soil solution, since the maximum concentration of the soil solution, except for soil crusts formed by surface evaporation, would occur at the bottom of the root zone. It follows from the above two equations that for irrigation water of a given quality (EC_{iw}) and for a given crop-climate complex accounted for by D_{cw}, the depth of the irrigation water to be applied and the depth of the drainage water to be extracted out of the root zone will be uniquely determined in relation to a specific level of salinity (EC_{dw}) that must be maintained in the root zone. The ratio $\frac{D_{dw}}{D_{iw}}$ expresses the leaching requirement, that is the fraction of water that must be leached down through the root zone to control the soil salinity at a specific level.

The inter-relationship between irrigation, leaching and drainage with respect to the water table is obvious. While irrigation and water application for leaching greatly augment the recharge of the ground-water formation, the surface as well as sub-surface drainage affects the discharge conditions. The vital role played by the water table in relation to the salt problem has already been discussed.

If these three aspects are duly attended to collectively and individually on all development projects for water and land resources, it should be possible to keep the problem of salinity and alkalinity within reasonable limits. Properly co-ordinated control of these should, indeed, form the basis of all improved agricultural activity and water management on the farm and the land.

IRRIGATION

The principal salt problem of economic importance arises when previously non-saline soils become saline as a result of irrigation. It is, therefore, of foremost importance that when new irrigation is introduced, measures safeguarding against the possibilities of salinization be adopted from the very beginning.

The first necessity when undertaking irrigation schemes is to assess very carefully the quality of water available under the project in relation to the soil, climate and cropping pattern. This is particularly important because the urge and the pressure to use high-salinity water is very marked in arid zones, where the total water resources are very meagre and inadequate as compared with the land resources.

While small amounts of salts in the water may even stimulate crop growth, water with high salt content should not, in general, be used for irrigation of soils with low infiltration and drainage rates. The higher the salt content, the greater the leaching requirement; it may not be possible to meet this requirement without bringing about a serious rise in the water table. Several instances have occurred in the author's experience in which irrigation with high quality irrigation water has rendered the soil completely barren in 15 years. Experiences of this kind have caused people to use more water to keep the soil productive and to raise the water table, with more severe consequences.

If the water has a high sodium content, it becomes even more important to weigh the consequences carefully before launching an irrigation project.

It has been observed on canals in northern India that the average water loss by seepage is 17 per cent from the canals and branches, 8 per cent from the distributaries and 20 per cent from the field channels. Thus to deliver 100 cusecs to the cultivator's field, 182 cusecs will have to be let in at the canal head. Out of 100 cusecs applied to the field, 30 per cent go to the subsoil and only 70 cusecs are actually utilized by the crop. In other words, out of 182 cusecs released at the head of the canal, 112 find their way to the subsoil water. Lining of the canals and of the field channels to prevent seepage should, therefore, be treated as an integral part of the project wherever a serious rise in the level of the water table is feared.

Various materials and methods for lining have been tried in India. They can be divided into the following broad categories: (a) cement or lime concrete; (b) stone masonry set in cement or lime mortar; (c) bricks, set with cement mortar; (d) asphalt, bitumen and their derivatives, using jute cloth impregnated with the material; (e) treatment with chemicals such as sodium carbonate alone or in combination with Bentonite (calcium-aluminium-silicate), so as to produce impervious sodium clay; (f) soil compaction and stabilization, including natural staunching by the inclusion of the salt deposit.

While some of the methods already tested have been found feasible under particular conditions and employed on a few projects, there is a profound need for continued and intensified research to evolve a material combining cheapness, effectiveness and ease of handling and maintenance. Recently, good prospects seem to have been held out by the use of plastic material, particularly for the lining of small channels. The material is still under investigation in various research institutes in India.

Another risk to be safeguarded against under irrigated conditions, particularly where there is a danger of a high water table, is the application in the field of water far beyond the normal leaching requirements. Although considerable advances have recently been made in the scientific application of irrigation water in accordance with the field capacity and wilting point concepts, it has not yet been possible to bring home to the cultivators the advantages of the improved methods and practices. It is a common observation that the wastage of water by over-application occurs more in gravity-flow canals than in other works such as wells, etc., where the water is lifted by the cultivators themselves. If the water in the gravity canals is delivered to the cultivators on a volumetric basis instead of on a crop area basis, as is the case at present in India, it may be possible to improve the situation considerably. The unsuccessful attempts made in this direction in India, however, bring out the difficulty of effecting this change unless agricultural practices are more advanced. It is therefore necessary that the cultivators should be educated in the use of correct irrigation practices by proper extension and persuasive measures. One of the ways of attempting this would be actually to demonstrate the importance and the advantages of improved practices on specially arranged plots near the cultivators' fields. To supplement persuasion by some compulsory measures, a nominal irrigation cess could be levied on the entire irrigable area in the command of a project irrespective of the fact whether one takes water or not.

A point to remember with regard to the optimum application of water (as judged by the criterion of the degree of salinity) is that insufficiently deep irrigation carried out at frequent intervals should be avoided as far as possible. Short, frequent irrigation is likely to result in increased evaporation and a greater tendency for salts to move upward in the top soil. It may be desirable to apply irrigation water when the moisture content of the root zone has been reduced to as near to the wilting point as other considerations, such as maximum crop production, etc., will allow.

Irrigation methods for applying water to the soil are also related to salinity and should, therefore, be selected with prudence. Irrigation methods which provide uniformity of application and downward movement of water through the soils favour salinity control. The border, the check and the basin methods of irrigation, which involve ponding or flooding water over the soil surface, give greater uniformity of application than the furrow or corrugation methods. The former are, therefore, preferable from the point of view of salinity control. The length of run, the size of the stream, the slope of the land and the time of application are also factors which govern the uniformity of application, and are therefore important. Careful levelling of land makes a more uniform application of irrigation water possible and is, therefore, desirable.

Sprinkler irrigation is not an economic method where a salinity problem exists. There is a tendency to apply too little water by this method and unless a special effort is made, leaching to maintain a proper salt balance will not be successfully accomplished.

Leaching

In arid and semi-arid regions where natural leaching of salts by rainfall has not taken place, the leaching process can be accomplished artificially by ponding an appreciable depth of water on the soil surface by means of dykes or ridges. On sloping land, dykes can be built along contour lines and the flooding carried out in narrow strips. The leaching requirement of water is related to the depth and salt-content of the soil. These factors can be correlated by an expression of the type:

$$\frac{D_{lw}}{D_s} = A\,\frac{(EC_e)_i}{(EC_e)_f} + B$$

where D_{lw} is the depth of water leached through a depth of soil D_s and $(EC_e)_i$ and $(EC_e)_f$ are the average electrical conductivities of the saturation extract in the soil profile, initially and finally, that is before and after leaching respectively. A and B are constants which may vary from location to location. From leaching experiments at several locations it has been found that in the case of highly saline soils one foot of water for each foot depth of soil will usually provide enough leaching to allow crops to be grown satisfactorily.

Application of water for pure leaching is often considered uneconomical and the operation is, therefore, coupled with suitable cropping to make the process a financial success. The soil reclamation technique developed in the Punjab links the process of leaching with the cropping of rice, followed, when land shows improvement, by leguminous crops such as barseem, sanji or gram.

Results in the Punjab show that such areas, which are mildly saline and in which the alkalization of land has not proceeded very far (*p*H between 8.5 and 9.0), may require only one rice crop, followed by proper crop rotation to reclaim them. For those areas, where the salt content is still higher and alkalization somewhat more advanced (*p*H between 9.0 and 9.5), two rice crops may be necessary. Lands where alkalization is still further advanced (pH higher than 9.5) are more difficult and expensive to reclaim, the reclamation being a long-drawn out affair. For leaching and the growth of the first rice crop an irrigation depth of 5–5.5 ft. of water has been found ample in the Punjab, and an area of about 50 acres of saline land can be put under reclamation with one cusec of water.

Drainage

Irrigation inevitably involves the risk of excess water entering the soil (e.g. as a result of leaching, seepage or waste)—hence the need for adequate drainage. It is highly desirable, therefore, that every irrigation project should have as an essential counterpart a drainage programme, and that the latter should be initiated and continuously integrated with the development of the irrigation system in order to maintain over-all and efficient control of the water and its salinity content. And the earlier the drainage problems are attended to in the course of the development of an irrigation project, the greater will be the possibility of solving them.

In order to make it comprehensive and effective, the design and layout of a drainage system should take into account the following factors: (a) stabilization of the water-table at a proper, safe level below the ground surface; (b) irrigation and leaching requirements of water that must be passed through the root zones; (c) ground-water formation and its existing recharge and discharge boundary conditions; (d) rate and direction of ground-water movements; (e) soil stratography.

It is obvious that any drainage survey should include the study of both topography and ground-water hydrology. While topography may be read on the contour maps, the study of ground-water hydrology requires a properly designed network of observation wells, located, sunk and studied in a scientific manner. A close study of the factors mentioned above should also govern the choice of the drains, i.e. whether they should be open drains or underground tile drains. As a rule, it may not be desirable to have tile drains as the main drains. The lateral drains may be tile drains or open drains; the choice should depend primarily on the stratography and the depth to which the water-table is to be lowered. Excavation and maintenance of open seepage drains may be difficult when the depth of digging involved below the line of saturation is appreciable. The situation may suggest the use of underground tile drains. On the other hand, the lack of drainable strata at the proper depth below the ground surface may make drainage by tiling impracticable.

The proper placement of drains is of considerable importance in the design of a drainage system and should be carried out scientifically. As a general rule, the drains should be located in a pervious strata comprising sand and gravel layers. The placement and the depth of the drains will also be related to the elevation of stabilization of the water-table. The drain should be oriented, as nearly as is reasonably possible, perpendicular to the direction of the ground-water flow. Drains which cut across and intercept sand and gravel deposits provide much more effective drainage than those dug parallel to these deposits.

The spacing of drains is another factor which must be determined by the texture and the permeability of the soil. Whereas drains in relatively permeable and clay soils may need to be placed very close together (i.e. at a distance of 150–200 ft.), spacing of 800 ft. or even more may be adequate for sandy and gravel soils. Quite often the reason for the drainage problem of a tract may be the long neglect of its drainage ways. For continual effectiveness of a drainage system, it is important that maintenance should be undertaken regularly. Preventive measures may often be efficacious in keeping the maintenance problem within bounds. Sloughing in of sides may be successfully tackled by flattening side slopes, and the over-burden of the soil relieved by setting back the banks and finally by staking and bushing. A gravel pack filter installed around the tile drains may prevent sediments from entering the tile drains.

Although drainage by pumping out ground-water through tube-wells or otherwise has been successfully effected at some locations, it is doubtful if it will lead to beneficial results in all cases. First, it is necessary for proper pumping that the strata tapped should be permeable and have good ground-water flow. Secondly, the aquifer tapped should not be confined but should have a porous connexion with high water that is reasonably free of water-logging and excess salinity. Unfortunately, water-logged areas are often associated with relatively less permeable strata where ground-water pumping cannot be of much help.

RÉSUMÉ

Aspect hydrologique du problème de la salinité en agriculture; comment lutter contre la salinité par une utilisation plus rationnelle des eaux dans les régions arides et semi-arides (et notamment en Inde) (J. K. Jain)

Terminologie et définitions.

Introduction: nature et données principales du problème de la salinité.

Hydrologie et salinité: exposé détaillé des divers facteurs hydrologiques (précipitation, évaporation, variations de l'humidité édaphique, montée de la nappe phréatique, irrigation, quantité d'eau et drainage, etc.) et de leur rôle dans le processus de salinisation.

Le problème de la salinité en Inde: aperçu de l'importance relative des données hydrologiques.

La lutte contre la salinité et l'alcalinité par une utilisation plus rationnelle des eaux: exposé détaillé des principes de base à observer et des solutions concrètes possibles notamment en matière d'irrigation, de lixiviation et de drainage.

DISCUSSION

C. Gomella. En ce qui concerne l'imperméabilisation des canaux:

(1). Quels procédés autres que l'emploi des matières plastiques ont été utilisés?

(2). Dans le cas des matières plastiques, quelles sont les méthodes et les matières qui ont donné les résultats les plus satisfaisants?

J. K. Jain. (1) The different materials and methods tried in India may be classified as follows: (a) cement or lime concrete; (b) stone masonry set in cement or mortar; (c) bricks using cement mortar; (d) asphalt, bitumen and their derivatives employing jute cloth, impregnated with the material; (e) treatment with chemicals such as sodium carbonate, alone or in combination with Bentonite (calcium-aluminium-silicate), thus producing impervious sodium clay; (f) soil compaction and stabilization, including natural staunching by inducing silt deposit.

(2). As regards plastic materials, experiments are being tried in India with samples of polythene sheeting obtained from Australia. This method is reported to have been found efficacious in Australia for preventing seepage losses from small tanks and storage reservoirs. As far as India is concerned, the method is in an experimental stage.

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SOIL SALINITY IN WEST PAKISTAN AND MEANS TO DEAL WITH IT

by

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SUBSOIL WATER TABLE CONDITIONS

The land of the former Punjab and the Sind is very extensive and flat, with a surface slope of hardly a foot per mile. The development of the irrigation system, spreading a discharge of 96,000 cusecs in the Punjab plains, caused infiltration of water into the subsoil. The construction of weirs and barrages across the rivers of the Indus Basin raised the general level of the rivers. The construction of canals, the majority carrying a discharge varying from 6,000 to 14,000 cusecs, dug in the porous alluvium, and with full supply levels on the average higher than the land surface, contributed large infiltration into the subsoil formation; this resulted in a rise in the water table.

During the last 60 years, with the opening of the country, crossed by innumerable canals, railways, roads and other artificial constructions that obstruct the natural surface drainage, more water was added to ploughed lands and seepage occurred from large perennial canals. The water table started to rise rapidly, then continued to do so more slowly as its level approached that of the surface. A recent examination for Rechna Doab [4][1] has shown that this rapid rise, which continued till the water table came within 20–25 ft. of the surface, was of the order of 1.3–1.5 ft. per year. The rise within a depth of 20–10 ft. below the surface was slower, the rate of rise equalling 0.3–0.6 ft. per year In areas with the water table at 10 ft. or nearer to the surface the rise is at the rate of 0.07 ft. per year. The rapid rise of 1.3–1.5 ft. per year was the result of infiltration from various sources without evaporation or transpiration losses.

All the water being added to the formation was either being retained in the pores of the alluvium or being drained away at a slow speed corresponding to the permeability of the medium and to the driving head. The slow rise can be a result of a decrease in the driving head and of the effects of evaporation, or possibly of drainage. The present rise of 0.07 ft. a year is definitely due to the above-mentioned causes, particularly evaporation and transpiration by plants, and surface drainage.

The area with a water table between 0 and 5 ft. below the surface has reached a stable situation, there is a slow change in the area in which the water table is between 5 and 10 ft., and the area with a water table between 10 and 15 ft. and lower is definitely being reduced with the rise of the water table.

A typical rise in the water table in the region of the Upper Chenab Canal is illustrated in fig. 1.

CAUSES OF THE RAPID RISE OF THE WATER TABLE IN THE CANAL REGIONS

The Punjab plains have been formed by the deposition of the alluvium brought down by the rivers. At some places it is 10,000 ft. thick. The plains are so extensive

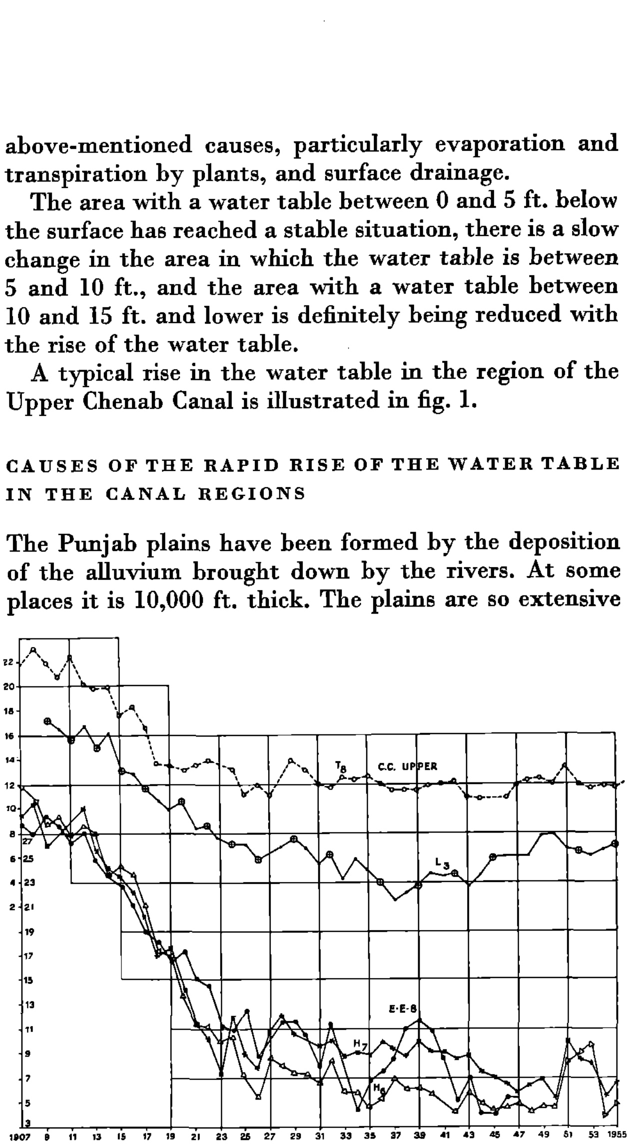

FIG. 1. Rise in wells in the zone of Upper Chenab Canal W–R to N–S. Period 1907 to 1955.

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[1] The figures in brackets refer to the bibliography on page 124.

that deposition of the alluvium of various grades—sand, silt and clay— took place in the form of small patches. The clay deposits in particular are in the form of small lenses, a few square miles in area and located in a quite haphazard manner at different elevations and positions.

This type of formation has a serious effect on the subsoil flow, so that water entering it and flowing towards the lower elevations is obstructed every now and then by fine sand, silt or clay deposits. Permeability of clay deposits being within a range of 1–0.01 $\times 10^{-6}$ ft. per second, a flow under a gradient of 1 ft. per mile is hardly $^1/_{10}$ ft. in a year. The permeability of the sand formation and silt is, however, considerable [5].

If the subsoil flow is discounted then, on the basis of a rapid rise, true seepage from a certain zone of the canal can be estimated. This conception gives an order of seepage equal to 300 cusecs from 2,800 sq. miles of the Upper Chenab Canal region and 700 cusecs from 6,200 sq. miles of the Lower Chenab Canal region.

Under the present irrigation system of the region, this type of formation is subjected to seepage from canals; this has caused the water table to rise by 0–5 ft. in 760,000 acres [6] of the Rechna and Chaj Doabs, so that under the influence of the high order of infiltration from a high head canal, free water is to be found on the surface of strips a few feet wide running along the two sides of the canal, and all the low-lying areas with sandy top-soil are filled with free water. Such areas constitute about 22,000 acres [1] in the Punjab.

SALTS IN SUBSOIL WATER

Water infiltrating through a formation charged with soluble salts will carry salts with it. If the condition of the area is such that this infiltrated water can seep away, then there is a possibility of a decrease in the concentration of salts of the formation and the subsoil water will be good for irrigation and consumption. However, surveys of the water of the *doabs* have shown that deeper water is invariably unfit both for consumption and for irrigation. At some places even shallow water is also unfit. Sometimes brackish and fresh water appear at the same elevations, and in some cases even deeper zones have fresh water. The occurrence of subsoil water in this way confirms the view that there is an insignificant subsoil flow and at some places clay lenses are holding up the flow even at quite high elevations and infiltration of rain and irrigation water is unable to replace it.

The density of salt water being higher may also cause difficulty for replacement by fresh water. The fresh water appears only at places where the brackish water has flowed away, giving place to this infiltrated water.

SALTS IN THE WATER OF RIVERS

Many systematic analyses of the water of our rivers have been carried out [11]. The latest was carried out at the suggestion of Eaton [9], and considerable data has recently been collected by the Ground Water Organization of the Punjab [12]. All the authorities are of the opinion that salts carried by our rivers do not harm the soil by increasing the salt concentration. A typical analysis of a river water sample is shown in Table 1.

In order to estimate the sediment content it was necessary to know the dissolved content of the river water. This was daily determined practically for several sites. In the field, a hydrometer was used for such estimates. Occasional river water samples from perennial rivers and regular water samples from flash streams were also analysed. The salt content, as determined by filtering, drying and weighing in the laboratory, is given in Table 2 for 11 rivers.

A study of these figures leads to the conclusion that the dissolved content of perennial rivers is reasonably low. There is a tendency towards some increase with the fall in temperature or discharge; this may be due to the fact that during the winter some addition to the discharge of the river comes from seepage water.

The flash streams, which bring high discharges during monsoon rains in particular, gave a higher order of dissolved contents. When water from these small streams is mixed with main streams, the salt content decreases. It is thus concluded that the salts of the rivers of the Indus Basin lie within the range of 150 to 300 parts per million parts of water.

A study of the above results shows that the quantity of salts in the water of our rivers is not great, but one point needs consideration, and that is that we have been applying water in insufficient quantities to the land for the last three-quarters of a century, and with little free drainage. There is consequently a possibility for these salts to remain in the soil formation, thus increasing the concentration and affecting the yield.

The net result of these physical changes—the application of river water to fields without much drainage and many other factors—has been the spread of salinity in West Pakistan. It was estimated in 1940 [1, 7, 11, 17] that about 40,000 acres per year were going out of cultivation, but the latest surveys in 1955 [12] have shown that the rate has increased to 70,000 acres per year, and it is further estimated that this rate of deterioration is on the increase. In 1952, Dr. Asghar [1] stated that out of 11.3 million acres of irrigated land, salts were visible at the surface in 2.3 million acres. As a result of the 1955–56 survey, Larocque [12] stated that in a survey of 9.5 million acres in the Rechna Doab, the salts distribution was as follows: (a) 1,330,000 acres, representing 14 per cent, have completely gone out of cultivation; (b) 1,630,000 acres, representing 17 per cent, are 50 per cent productive; (c) 4,600,000 acres, representing 48 per cent, are 50–85 per cent productive; (d) 1,940,000 acres, representing 20 per cent, are more than 85 per cent productive.

The situation calls for suitable action and in the ensuing pages some suggestions to counteract this state of affairs are put forward.

TABLE 1. Comparison of quality of river water samples[1] taken in spring and autumn of 1952

Sample no.	Source	Date	Discharge cusecs	EC × 10^6	Total solids ppm.	Boron ppm.	SiO_2 ppm.	Milli-equivalent per litre								
								Ca	Mg	Na	K	CO_3 HCO_3	SO_4	Cl	F	NO_3
22032	Sutlej: Suleimanki	Mar. 20	4 769	284	198	.06	8	1.52	.75	.75	.13	2.05	.43	.60	.01	.01
22139	Sutlej: Suleimanki[2]	Aug. 24	259 455	324	573	.07	14	2.45	.63	.48	.18	2.40	.36	.15	.01	.04
22033	Ravi: Boat Bridge	May 12	4 041	201	148	.02	11	1.35	.55	.19	.10	1.65	.36	.15	.01	.00
22144	Ravi:[2] Shahdra	Aug. 2	9 153	207	207	.05	14	1.28	.61	.28	.16	1.83	.07	.15	.01	.02
22034	Chenab: Marala	Mar. 11	11 380	226	166	.02	6	1.38	.74	.21	.08	1.75	.48	.10	.01	.02
22142	Chenab: Marala	July 29	70 844	179	102	.09	6	1.42	.25	.12	.08	1.60	.21	.10	.01	.01
22141	Jhelum: Mangla	Aug. 7	59 640	231	137	.03	12	1.98	.34	.15	.08	2.20	.20	.05	.01	tr
22143	Indus: Kabalagh	Aug. 2	242 500	301	169	.05	7	2.69	.25	.22	.10	3.10	.02	.14	tr	.01
22036	Indus: Sukkur	Jan. 30	31 000	370	244	.19	8	2.12	.86	.88	.14	3.00	.25	.69	.01	.00
22035	Indus: Karachi[3]	Feb. 27	2 751	418	270	.30	11	2.08	.97	1.04	.18	2.85	.81	.62	.01	.00
22140	Panjnad: Panjnad	Aug. 22	200 598	253	149	.07	9	1.71	.56	.42	.10	2.15	.33	.20	.02	.02

1. Samples collected under supervision of Dr. R. F. T. Farrant, Director, Irrigation Research Institute, Public Works Department, Lahore. Analyses by U.S. Salinity Laboratory, Riverside, California, U.S.A.
2. Organic matter accounts for lack of balance between cations and anions and for high dissolved solids value.
3. Estimated 95 per cent return flow.

REMOVAL OF SALTS BY LEACHING

In the soils of West Pakistan the quantity of salts of potassium and magnesium is exceedingly small as compared with that of sodium, and this is equally true for chlorides as compared with sulphates. Saline soils also contain salts of calcium sulphate, calcium carbonate and magnesium carbonate, which are sparingly soluble. Alkali soils are not extensive in West Pakistan and occur only in small patches. During the reclamation of these soils frequent and deep ploughing is necessary, in addition to the chemical treatment.

For reclamation of saline soils by leaching, rice is grown which has a greater tolerance to a high percentage of salts. Water is kept standing in the fields for some months, during which the crops grow. The percolation through saline soils is further improved by the growing crops, the roots of which penetrate the soil and make it more pervious. There are also other standard procedures adopted to complete the reclamation operation [15].

DIFFICULTIES OF SUCCESSFUL LEACHING IN WEST PAKISTAN

In the two *doabs* of the Punjab worst affected by the salinity problem, 4.83 million acres of land, comprising about 50 per cent of the total land in Rechna and Chaj Doabs, have a water table within 10 ft. of the surface. Here salts can easily rise up and accumulate close to the surface. In about 0.7 million acres the water table is within 5 ft. of the surface, so that the zone where salts can be redistributed is considerably reduced. This is particularly the case for silty soils which have a great capillary activity. Thus the soil zone where salts can be redistributed is limited. The second factor essential for the success of the reclamation operation is the draining away of salt-charged water. To achieve this the following methods are used: surface drains; tile drains; drainage by tube wells.

The following is a study of the merits and success of each type, as applied to this country.

TABLE 2. Dissolved salts estimated in the laboratory by filtering, drying and weighing; monthly mean for one year only

Sample no.	River	Site	Nature of river	Period	Year	Mean dissolved contents in parts per million
1	Jhelum	Mangla	Perennial	April	1957	140
2	Jhelum	Mangla	Perennial	August	1957	170
3	Jhelum	Mangla	Perennial	September	1957	180
4	Jhelum	Domel	Perennial	May	1957	250
5	Jhelum	Domel	Perennial	June	1957	230
6	Kishanganga	Muzzafar abad	Perennial	May	1957	180
7	Kishanganga	Muzzafar abad	Perennial	June	1957	230
8	Kunhar	Ghari-Habibullah	Perennial	May	1957	250
9	Kunhar	Ghari-Habibullah	Perennial	June	1957	140
10	Indus	Kalabagh	Perennial	May	1957	200
11	Indus	Kalabagh	Perennial	June	1957	300
12	Indus	Kalabagh	Perennial	July	1957	250
13	Poonch	Palak	Perennial	April	1957	150
14	Poonch	Palak	Perennial	June	1957	250
15	Harrow	G.T. Road	Perennial with flash floods	February	1957	210
16	Harrow	G.T. Road	Perennial with flash floods	March	1957	270
17	Harrow	G.T. Road	Perennial with flash floods	April	1957	230
18	Harrow	G.T. Road	Perennial with flash floods	May	1957	200
19	Harrow	G.T. Road	Perennial with flash floods	June	1957	200
20	Harrow	G.T. Road	Perennial with flash floods	July	1957	190
21	Harrow	G.T. Road	Perennial with flash floods	August	1957	250
22	Harrow	G.T. Road	Perennial with flash floods	September	1957	210
23	Harrow	G.T. Road	Perennial with flash floods	October	1957	200
24	Soan	Mukhad Road	Perennial with flash floods	June	1957	210
25	Soan	Mukhad Road	Perennial with flash floods	July	1957	240
26	Soan	Mukhad Road	Perennial with flash floods	August	1957	200
27	Soan	Mukhad Road	Perennial with flash floods	September	1957	210
28	Soan	Mukhad Road	Perennial with flash floods	October	1957	260
29	Kahan	Rohtas	Rain run-off stream	January	1957	170
30	Kahan	Rohtas	Rain run-off stream	February	1957	215
31	Kahan	Rohtas	Rain run-off stream	April	1957	280
32	Kahan	Rohtas	Rain run-off stream	July	1957	300
33	Kahan	Rohtas	Rain run-off stream	August	1957	280
34	Kahan	Rohtas	Rain run-off stream	September	1957	210
35	Kahan	Rohtas	Rain run-off stream	October	1957	175
36	Siran	Thapla	Perennial with flash discharge	January	1957	330
37	Siran	Thapla	Perennial with flash discharge	February	1957	240
38	Siran	Thapla	Perennial with flash discharge	March	1957	270
39	Siran	Thapla	Perennial with flash discharge	April	1957	360
40	Siran	Thapla	Perennial with flash discharge	May	1957	350
41	Siran	Thapla	Perennial with flash discharge	June	1957	170
42	Siran	Thapla	Perennial with flash discharge	July	1957	200
43	Siran	Thapla	Perennial with flash discharge	August	1957	250
44	Siran	Thapla	Perennial with flash discharge	September	1957	220
45	Siran	Thapla	Perennial with flash discharge	October	1957	190
46	Kanshi	Gujar Khan	Flash stream	June	1957	230
47	Kanshi	Gujar Khan	Flash stream	July	1957	220
48	Kanshi	Gujar Khan	Flash stream	August	1957	225
49	Kanshi	Gujar Khan	Flash stream	September	1957	180
50	Kanshi	Gujar Khan	Flash stream	October	1957	200

OPEN DRAINS

Open drains are of two types—flood water drains and seepage drains. Flood water drains are designed to carry away the run-off of the area before it becomes seriously detrimental to crops. They are never designed to carry the maximum run-off and their capacity is often a certain fraction of that maximum. There are about 13.5 miles of drains in Techna Doab designed to carry a discharge of 13,832 cusecs, and 950 miles in Chaj Doab meant to carry 2,901 cusecs [1]. The flood water drains are not very deep, usually have the same slope as that of the country and become ineffective during floods as the outfalls are also flooded with high water levels and this results in overflow of the drains which, instead of working as carriers of flood and rain water, add to the flooding of the land. These drains are threatened by growth of weeds, choking-up by silt deposition and the collapse of banks, etc.

There are no systematic seepage drains in the country. Some of the flood water drains do serve as carriers of seepage water but actually they are not designed and maintained for this purpose.

In the field, a water table 3 ft. below surface is not detrimental to the successful growth of common crops [6], and for special crops like cotton an upper limit of the water table of 6 ft. is sufficient. To keep the water table at 3 ft. below the surface, field drains may be dug 4–6 ft. deep and at a suitable distance from one another. These can discharge into the carrier drains that carry the water into the main seepage drains that take away the seeped water.

To be efficient a seepage drain must be deep, as the topmost flow line in a formation is like a free surface and, when it opens out on the discharge face, its point of emergence is always above the water level in the drain. The water level in the drain controls the position of the topmost flow line. The rise or fall of the water level in the drain affects the point of emergence on the discharge face and this effect is communicated to the soil formation. Now, in a seepage drain, water must ooze out at the sides, carrying soil particles along with it which invariably get deposited in the bed of the drain and reduce its efficiency as a whole. Again, when the country is flat, the slope can neither carry away the sediment particles flowing into the drain with water, nor stop weeds growing and fungus forming at the surface. This stagnant water further reduces the efficiency of the drain.

Improved design of a seepage drain

There is no solution to the last-mentioned defect, but as regards construction some measures may be suggested which can improve the working of seepage drains.

If the design of a drain allows for wide berms, say 10 ft. on each side, with a small central cunette to carry away the seepage water, the banks will continue to fall in and fill the berms, and there will be sufficient space for the coarse grades of soil to accumulate, hence only the finer clay particles will pass into the cunette to be carried away (fig. 2).

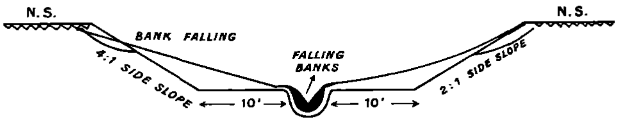

FIG. 2. Drain with cunette; sides partially lined.

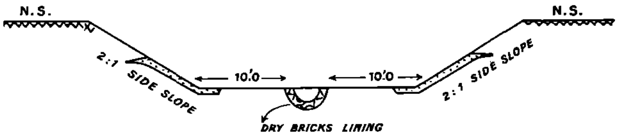

FIG. 3. Drain with cunette; side slopes unlined.

The cunette should have a stable section lined with dry unpointed bricks.

Another suggestion is to line 4–6 ft. of the sides of the drain with porous concrete made by using brick-bats. This will eliminate the chances of falling banks. This suggestion is illustrated in fig. 3.

To be effective the slope of the drain must be greater than that of the land. It will thus become necessary to provide masonry sumps every few miles to collect and pump out the water brought in by the seepage drain.

The problem of weeds

The size of the cunette should be decided in the light of the seepage water it is to carry, which should not overflow onto the berms. Weeds are difficult to control; countries which can afford chemical weed killers have tried them, but in Pakistan such chemical products are neither available nor effective because of seepage. Occasional manual removal of weeds will have to be tried.

TILE DRAINS

Tile drains are used extensively in America, the Netherlands, and some other rich countries of the world. This is a scientific method of drainage without many of the disadvantages of open drains. Tile drains do not spoil the land, do not interfere with movement at the surface, are little threatened by weeds or by falling-in of the banks, which impair the efficiency of the drain, or by hydraulic defects of free surface. Despite all these advantages, under the conditions prevailing in Pakistan, their use is at present difficult. In 4.83 million acres of the Rechna Doab and Chaj Doab the water table lies within 10 ft. of the surface and laying tiles after digging in the slush is a problem.

For the most part the region has a thick soil crust. The previous sandy zone is comparatively limited. To lay tiles in relatively impervious soil may not be as effective as to lay them in pervious sand, as is the common practice. The result is a closer spacing of the drains.

Tile drains should have a steep slope to carry away soil particles and prevent them from settling in the drain. This will deepen the position of the drain every few miles, where sumps will have to be provided to pump up the water brought in by the drain. The availability of good shrouding material is another problem; shrouding by shingles is too costly. Shrouding made of over-burnt bricks may be worth a trial.

The cost item is another big problem. For their efficient working, the distance between the drains may need to be fairly small and all processes of dewatering, laying, providing for materials and, finally, for pumping the seeped water for disposal, will increase the expenditure considerably. Both the types of drains considered above are used for drainage of the top soil. They can have no influence on the deeper saline water nor will it be possible by their installation to dewater thick soil formations. This type of deep drainage is only possible by pumping from deeper formations; this we shall now consider.

DRAINAGE BY PUMPING OF SOIL WATER

Before considering this method of drainage, it will be worthwhile to repeat some of the important conclusions which are well known for the land of West Pakistan.

1. To counteract salinity, we need large volumes of water to wash down the soluble salts.
2. Water charged with a large amount of soluble salts must be drained away, but the formation of the Punjab is such that there is very little natural subsoil flow; it is mostly blocked by clay lenses.
3. Areas where subsoil flow is completely blocked by clay lenses have water unsuitable for irrigation and if this is pumped out there will be a possibility of its replacement by fresh water from the present sources of infiltration.
4. Subsoil brackish water does not possess as large an amount of salts as the surface accumulation, which is sometimes more than 0.2 per cent of the dry soil. Washing the soil heavily charged with salts by saline water can reduce the salt percentage considerably and can make the soil fit for crops.
5. The alluvium formations are usually fairly uniform [3, 16], so that such sands have a high permeability coefficient. This is true for the Punjab formation as well, the permeability coefficient of which is fairly high, as mentioned at the beginning of this note. The result is that the formation yield is considerable, though sands of the coarse type are seldom found in these regions. The percentage of clay and fine particles is also very low—it seldom exceeds 5 per cent in a good water-yielding sand.
6. The most common types of aquifer formations in the Punjab are such that within a depth of 100 ft. of the surface, 50 ft. of good, water-yielding, medium-grade sand is always available. The rest of the formation consists of about 20–30 ft. of fine sand, and the same quantity of soil and dirty sand.
7. Where the water table is high, say within 10 ft. of the surface, ordinary centrifugal pumps have effectively been used to pump water, the pumps being located within 3–5 ft. of the spring level. Such wells, with strainers 50–70 ft. long and with a 10–16 h.p. motor, have yielded 1.0 to 2.0 cusecs of discharge.
8. Where discharge is needed, and the water table is deeper than 20 ft., the cost of keeping the pump-house deep in the soil and close to the water table will be high. Under such conditions a deep turbine pump costing three times as much as a centrifugal pump, can pump 2 to 3 cusecs from a strainer 50 to 70 ft. long, but this over-pumping can considerably shorten the life of the well.
9. A tube well with a strainer 50 ft. long, giving 1.0 cusec discharge, can easily function without deterioration for 10–15 years.
10. A tube well working with a depression of 10–15 ft. inside the well creates a lowering of the water table, in a radius of 100 ft., of a depth of 3–5 ft. If a large infiltration source is not close by, its effect can extend to 5,000 ft. around, after continuous pumping for a week, and the water table can be lowered by 1–2 ft. in this zone.
11. A tube well with a 100-ft. long strainer causes a movement of the subsoil water up to a depth of 120 ft., and with continuous pumping a deep formation of this kind can be cleared of brackish water, which is replaced by fresh water from infiltration sources.

    There are instances in which good water has turned brackish as a result of continuous pumping, but zones of such water are limited and continued intense pumping can create a storage of fresh water.

A study of these few remarks indicates the possibility of quick drainage of an extensive area, thus creating a zone for redistribution of salts in the earth and at the same time making available the much-needed water for washing down the salts. All 11 of the conclusions enumerated are in fact experimentally supported for the Punjab region of West Pakistan; thus a solution to our salinity problems lies in the pumping of subsoil water and its re-use on the land.

There can be some doubt as to the conditions under which the water of the formation will become heavily saline due to washing down of salts in the land surface. It is suggested that it may be so adjusted to make available the canal supplies during the periods when more water is available in the rivers and continue pumping the subsoil salt-charged water into the canals or the rivers, whichever source of discharge is available. In this way some of the saline water will be replaced by fresh water. This simple method of removing salinity of the land has not so far been attempted mainly because of (a) lack of knowledge of the hydraulics of tube wells; (b) heavy initial cost of installation; (c) cost of maintenance and operation.

HYDRAULICS OF TUBE WELLS

In the Punjab, after some experimental attempts, certain of the big tube well projects, such as Karol, Karnal and Rasul, were undertaken and completed. Several other minor projects—Chuharkana, Jaranwala, Sheikhupura, etc.—have also been taken in hand and completed during the last 10 years and at present there are hundreds of tube wells successfully functioning in these two *doabs.* The research work done at the Irrigation Research Institute [2, 11] has helped considerably to advance the knowledge about the hydraulics of tube wells.

Heavy initial cost of installation

The major problem has been the initial cost of installation. So far the idea on which the government and some of the private enterprises have been working was to install deep tube wells of up to 250–350 ft. in depth, with long, costly, strainers of large diameter. Private individuals can seldom bear such a cost.

More recently the various bodies studying this question have started to use a much cheaper strainer made of a cage of iron strips wound round with coir string. Strainers of this type only cost a dollar or two a foot, and at present hundreds of them are being successfully used in the *doabs* of the Punjab. The conception now gaining ground is that a tube well is just a hole made in the water-yielding formation, and maintained as such by any of a number of devices. The coir string strainer is, of course, one such device, which was tried and found satisfactory in the region. A still cheaper method is to use *munj* string made out of a weed that grows in abundance in the water-logged area of this country, where *munj* strings are used for innumerable purposes. This string does not deteriorate in water and is stronger than coir. Being a local product and much cheaper than imported coir, it can conveniently replace coir. In the case of large diameter strainers double or triple windings can be introduced as a safety measure. Countries short of iron can adapt this suggestion by making cages with wooden strips, or with bamboo rods fixed on iron supporting rings. These will form cheap, durable and efficient strainers.

Further research into the construction of a cheap type of strainer has shown that baked clay can form a very satisfactory and durable strainer. It can reduce the cost to an insignificant amount, hardly a dollar for a 10 ft. baked clay strainer. When used in the field, this strainer lowers the cost of installation to an insignificant amount. So far, intensive laboratory experiments have shown that its performance is excellent. Its durability is immense and there is no doubt that the behaviour of strainers of this type both in saline water and in laboratory tests has shown them to be structurally sound.

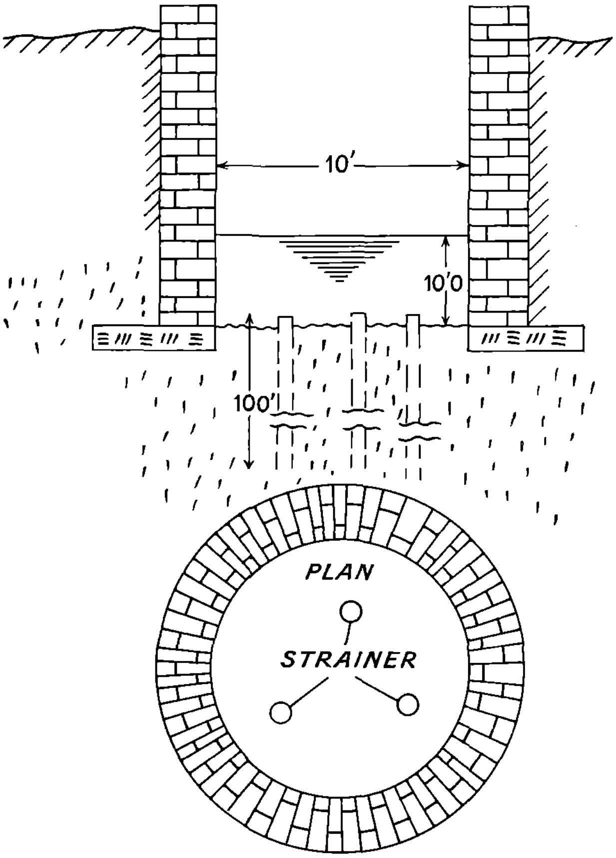

FIG. 4. Persian well with baked-clay strainers.

The cost of the strainer having been reduced, the cost of boring may be considerably reduced by using only 100 ft. of water-yielding aquifer. It is estimated that a baked clay strainer to pump 1.0–2.0 cusecs during a period of 10–15 years can be installed at a cost of not more than $100.

Again, there are several thousands of open wells where Persian wheels are used to draw water. Their water yield with bullocks is hardly 0.1 cusec. The source of infiltration in such wells is the sand bed, which is generally 30 sq.ft. in area. Some of the wells have a depth of 10 ft. of water. If these wells are provided with one, two or even three baked clay strainers which are placed in the bed of the well and distributed along the apex of a triangle, and if each 100-ft. long strainer has fine round holes, the yield of such wells (fig. 4) can be raised to feed a 2.0-cusecs pump. The cost of this type of installation will be very low, as it requires no blind pipe, no pump house, etc. An open well of large diameter will also be more efficient from the point of view of yield and operation. The source of water will be at a greater depth in the formation, and thus all the advantages of tube wells can be had from the old existing open wells.

RÉSUMÉ

La salinité des sols au Pakistan-Occidental et les moyens d'y remédier (M. Nazir Ahmad)

La salinité des sols est le problème le plus grave du Pakistan-Occidental. Cette situation menaçante serait due principalement aux dépôts alluviaux salins qui se produisent dans cette région. Diverses autorités contestent le rôle joué par les rivières du bassin de l'Indus dans l'accroissement de la salinité des sols. Le présent document montre l'ampleur du problème, et définit la nature et le type des sels contenus dans les sols et dans les eaux. Les infiltrations dues à l'existence d'un vaste réseau de canaux, la pratique intensifiée de l'irrigation, la longue persistance des eaux de pluie sur le sol, l'arrosage insuffisant des cultures et les conditions hydrologiques générales de la région sont autant de facteurs qui contribuent à aggraver le problème. La faible pente de la couche sous-jacente qui constitue une surface naturelle de drainage, les obstacles qu'opposent à l'écoulement les lentilles d'argile contenues dans cette couche, et le niveau élevé de la surface piézométrique réduisent les possibilités de recours à des contre-mesures naturelles.

La lixiviation des sols, qui élimine les sels solubles, ne produit pas non plus d'effets durables dans de vastes régions, en raison du niveau élevé de la surface piézométrique. Le drainage, qui est l'un des éléments essentiels d'une lixiviation efficace, ne peut se faire que par des procédés spéciaux, car les conditions actuelles rendent difficiles la construction et l'entretien de canaux de drainage de surface, qui se révèlent au surplus inefficaces en raison des propriétés hydrauliques des eaux de la couche sous-jacente, des mauvaises herbes et de la faible pente du terrain.

Les canaux de drainage en tuiles n'ont jamais encore été utilisés au Pakistan; ils seraient sans doute difficiles à installer en raison du niveau élevé de la surface piézométrique, de la faible pente du terrain et de l'absence de possibilités de déversement. Le seul système efficace est le drainage vertical par forages tubés, qui a déjà donné de bons résultats: il permet de faire circuler les eaux stagnantes, en créant ainsi une zone non saturée, et d'obtenir une baisse rapide du niveau de la surface piézométrique. Il améliore aussi l'approvisionnement en eau disponible pour dissoudre les sels solubles de la surface et les redistribuer dans le profil du sol.

Le grand obstacle à l'utilisation de ce procédé tient aux frais d'installation et d'exploitation. La question des frais d'installation a été résolue dans une certaine mesure, depuis qu'a été mis au point un modèle de drain peu coûteux — formé d'éléments de fer, de bambou ou de bois enveloppés de fibre de cocotier ou de corde de *munj*. Des centaines de drains de ce modèle sont en usage dans le pays depuis plusieurs années. L'emploi de drains d'argile cuite, qui se répand également depuis peu, permettra de réduire au minimum le coût des forages tubés. A l'heure actuelle, on utilise largement les drains d'argile pour accroître le rendement des puits ouverts et alimenter ainsi des pompes mécaniques. On espère que l'énergie solaire — dont les possibilités d'utilisation sont très grandes au Pakistan — fournira dans un très proche avenir un moyen économique de lutter contre la salinité des sols.

DISCUSSION

M. Ayazi. Do you use the water which comes from the well for irrigation immediately?

N. Ahmad. If the quality of water is good, which is usually the case, the water is used directly at the field. In certain cases, where the salt percentage of ground-water was high, this water was mixed with canal supplies and then used in the fields.

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II

PHYSIOLOGY OF PLANTS AND ANIMALS IN RELATION TO CONSUMPTION OF SALINE WATER

PHYSIOLOGIE DES ANIMAUX ET DES VÉGÉTAUX CONSOMMANT DE L'EAU SALINE

THE ADAPTATION OF PLANTS TO SALINE SOILS

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INTRODUCTION

In all soils there are some soluble salts that are absorbed by the plants. Among these salts the chlorides, mostly as sodium chloride, are in a special situation in as much as they are not needed by the plant for its nutrition. In particular, the chlorine ions are neither absorbed nor bound by the protoplasm. They accumulate as free ions in the cell sap. The nitrate and sulphate ions, on the contrary, undergo a reduction in the plant and are used by it for the formation of proteins. Only when they are absorbed in excess will they be found in the vacuoles as free ions.

The intake of ions may be an active process under consumption of energy or a passive one by diffusion. In the latter case it seems that the sulphates reducing the permeability of the cells are absorbed to a smaller degree.

The soil solution of salt soils, with its greater amount of soluble salts, has a higher osmotic pressure; as a result the absorption of water becomes more difficult for the roots of the plants. Schimper therefore claimed that salt soils were physiologically dry ones, and halophytes similar to xerophytes in their water economy. That is the reason why the plant physiologists (from Sachs in 1859 to Keller, Stocker, Benecke, Schratz, van Eijk, Adriani and Arnold) studied quite intensively the water economy of salt plants, thereby discovering that transpiration was reduced by augmented salt concentration. But investigations in recent years have shown that the problem of halophytes is less a problem of water economy than a problem of salt economy, i.e. a question of intake and accumulation of salts, and their effect on the plant protoplasm. The difficulties of water intake are overcome by the accumulation of salts in the cell sap. The osmotic counter-effect of the soil solution is compensated in this manner. The accumulation of salt in the plants provides an explanation of the fact that not only is the concentration of the salt solutions of importance, but also the composition of the salts.

THE KINDS OF SALT THAT AFFECT PLANTS

Salt soils on the sea coast are directly influenced by the sea-water, in which chlorides and sulphates everywhere predominate. Inland the composition of the salts is essentially influenced by the climate. We can observe this dependence very clearly in Ukraine (Gedroiz, Ivanova), where the climate becomes drier as we travel from north-west to south-east.

In the north-west, in the humid forest region, the rainfall is so high that we always find a downward water flow in the soil. The ground-water is acid and poor in minerals. The wet soils do not show any salt accumulation and tend to form oligotrophic peat lands (mires).

In the semi-humid forest-steppe region further south, the ground-water often contains calcium bicarbonate but no chlorides or sulphates and no sodium. During the summer, when evaporation exceeds rainfall, there occurs a high calcium carbonate accumulation on the soil surface ($p\mathrm{H} = 8$ or more).

In the semi-arid steppe region the ground-water already contains a small amount of sodium chloride and sulphate. In consequence sodium ions appear in the upper humus layer. These ions drive the calcium out of the humus complex and form sodium humate. During the wet season of the year sodium bicarbonate is formed by hydrolysis of the humus complex in the presence of carbon dioxide. At first the sodium bicarbonate is washed into the ground-water, and during the hot season it accumulates, together with humus soils, on the soil surface where the evaporation is very high. Black alkali soils with a very distinct vegetation are formed, their pH being of an extraordinarily high value.

The ground-water of arid, undrained regions is rich in sulphates and sodium chloride. As a result of high evaporation we observe the formation of white akali soils with a white salt crust on the soil surface.

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[1] See also H. Walter, "Standortslehre", *Phytologie*, Bd. III, 1, Stuttgart, E. Ulmer, 1951.

DISTRIBUTION OF SALINE PLANT HABITATS IN THE ARID ZONE

The presence of salt soils in the arid zone is not only a matter of climate but also a function of the edaphic conditions, i.e. it depends upon the nature of the outcropping rock. The content of chlorine in the earth crust only amounts to 0.07 per cent, and that of sulphur to 0.18 per cent. The large amounts of sodium chloride and sodium sulphate found in arid regions cannot originate autochtonically by the weathering of the minerals as is usually said, because minerals containing chloride are very rare. It is therefore preferable to distinguish the following possible origins of the salt: (a) As a result of evaporation from large water basins (Caspian Sea, Great Salt Lake in Utah, Tuz Gölü in Anatolia, etc.). (b) Out of sedimentary marine rocks in which the salt was included during the sedimentation in the sea. These salts were later protected against being washed out, and only where the rocks are exposed and weathered do the salts come to the soil surface again (marine tertiary, cretatious rocks, etc.). In arid countries where such rocks form salt soils, halophytic vegetation is very common. On the contrary, in regions with crystalline rocks it is often completely absent. (c) By aeolic sedimentation when salt-laden dust or marine spray is blown inland. For example, in the Namib desert the salt is transported by fogs about 50 km. (30 miles), from the sea coast into the interior. About 20 g. NaCl per m.^{2} are deposited on the desert soil every year. In Australia the salt deposit by rain at Perth is 30 g. per m.^{2}; 160 miles further east it is 2 g. (cyclic salt). Therefore the salt in the deserts is always of marine origin.

The distribution of salts and of salt vegetation depends also upon the relief. In the extreme arid regions with outcropping sedimentary rocks containing salt (Sahara) even the dry hamada-soils are saline and bare of vegetation. Otherwise the salts are washed from the elevations down into the undrained basins by the extremely rare rainfall. The halophytes are generally found in these depressions, where the salt soils are mostly wet. To know this is very important if one is to understand the physiology of these plants. Here they have ample water, but it is salt water and consequently the salt economy is much more important in the physiology of halophytes than the water economy.

THE BEHAVIOUR OF PLANTS TOWARDS THE SALTS

The salt concentration of black alkali soils is generally not high, but the reaction may be extremely alkaline. The species capable of withstanding these conditions are different from those growing on chloride-sulphate soils. Characteristic of black alkali soils of eastern Europe are: *Trifolium fragiferum, Triglochin maritima, Geranium collinum, Taraxacum bessarabicum, Puccinelia palustris, Peucedanum latifolium, Senecio racemosus,* etc. *Juncus gerardi, Scirpus maritimus,* and *Aster tripolium* also grow on chloride-sulphate soils if the concentration of salts is not too high. The physiology of these plants is not well known; we shall therefore consider especially the halophytes of the chloride-sulphate soils.

The easily soluble salts are absorbed by the plants without any difficulty. If they are toxic to the plants, even in low concentrations, the plants are unable to grow on salt soils and are classified as *nonhalophytes* (*glykophytes*).

Conversely, all species found on salt soils which are injured only by higher concentrations are called halophytes. Depending upon the position of the limiting values, we can distinguish between oligohalophytes, mesohalophytes and euhalophytes. But the limiting values for the plants of salt soils are not well enough known to permit an exact differentiation of these groups. Therefore let us distinguish only between: (a) *Facultative halophytes,* or salt-tolerant species, which have an optimum development on non-saline soils, but tolerate a certain amount of salt. We find these plants on salt soils, because here the competition of the nonhalophytes is less. (b) *Euhalophytes,* with an optimum on soils with a certain salt content. They may grow also on normal soils poor in salts, but they will not do so well. On such soils they eagerly take in every trace of the salts ever-present in the soil. The cell sap of these plants always contains more chlorides than that of nonhalophytes. The absorption of sulphates is always more limited.

Our crop plants nearly all belong to the group of nonhalophytes. Only a few of them are salt tolerant, i.e. datepalms, beets, onions, celery, raddishes and barley. The olive tree and the grape-vine are also not very susceptible.

Very small amounts of chlorides can have a favourable influence on nonhalophytes. An increase in productivity has even been reported as a result of their presence.[1] However, higher chloride concentrations seem to increase the permeability of roots. Greater amounts of salts are absorbed and, in consequence, the cells are injured even if the concentration in the cell sap is still below 9 atm. The deterioration of chloroplast can be prematurely noticed and a chlorosis is the result of it. Photosynthesis is also influenced in an unfavourable way. The leaves become distinctly succulent. The time of development is shortened (early flowering) or, when the injury is greater, the plant dies.

Most of the physiological investigations on the influence of salts are unsatisfactory, because the salt concentration is determined only in the soil, although for the reaction of the plant only the salts acting directly on the protoplasm are of importance. Hence it would be desirable in future studies to determine the salt concentration of the cell sap. It is not enough to measure the salt content of the plants per gramme dry weight, because it is impossible to learn from these figures anything

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[1] A. Arnold, *Die Bedeutung der Chloridionen für die Pflanzen,* Jena, G. Fischer 1955.

about the salt concentration. It would at least be necessary to know the water content of the plants.

Especially interesting physiologically, although of less importance for agriculture, is the behaviour of euhalophytes. We will now turn to this subject.

THE PHYSIOLOGICAL RELATIONS OF HALOPHYTES

We have just indicated that the water economy of halophytes is of less importance than their salt economy. It is therefore not permissible to compare them with xerophytes. There are no halophytes without any accumulation of salts in the cell sap. Contrary statements are erroneous.

If the salt content of the soil is low, the salt concentration in the cell sap, especially of chlorides, is higher than that in the soil solution. The osmotic pressure of the soil solution is therefore compensated or even overcompensated and the absorption of the water by the plant is not rendered more difficult. As the habitats of halophytes in the arid regions are mostly wet ones, there is always enough water in the soil. Habitats that are both dry and saline are bare of vegetation.

The following diagrams show the chlorides in the cell sap of halophytes as related to the total osmotic pressure of the cell sap (figs. 1 and 2). The chloride content of the American marsh plants always exceeds the sodium content (there is one exception, *Salicornia europaea*). One part of the chloride in the cell sap is therefore potassium chloride. The sugar content is very low. The amount of non-chlorides is normal. In the cell sap of African mangrove plants we determined only chlorides and sugars. The chloride concentration of halophytes is mostly between 20 and 30 atm. The osmotic pressure of halophytes is generally high, higher than that of xerophytes. The chloride content, expressed as a proportion of the total osmotic pressure, exceeds 50 per cent, but it may also be 90 per cent or even 97 per cent.

With the increase in the salt concentration in the soil the salt content of the cell sap also rises. Consequently the chloride concentration in the plant and that in the soil solution remain more or less equal. The mangroves referred to in fig. 3 show this very clearly. We have taken as examples those East African mangroves situated on open stretches of coast, away from estuaries. The concentration of the ground-water rises very evenly from 25.5 atm. on the shore to 33.3 atm. further inland, and from 25.9 atm. to 41 atm. in the upper soil layers. Accordingly, we find a regular zonation of the vegetation: a *Sonneratia*-zone, a *Rhizophora*-zone, a *Ceriops-Bruguiera*-zone and an *Avicennia*-zone. The osmotic pressure of the individual mangrove species shows an increase parallel to that of the soil solution. How the plants regulate their sap concentration in accordance with the changing soil solution we do not yet know exactly.

The roots of the halophytes do not absorb the unchanged soil solution, but only a very diluted one. As the water is transpired and the salt remains in the transpiring leaves, an accumulation of salts in the leaves should take place in the long run. The plants overcome this in different ways (Steiner), and we can distinguish the following types:

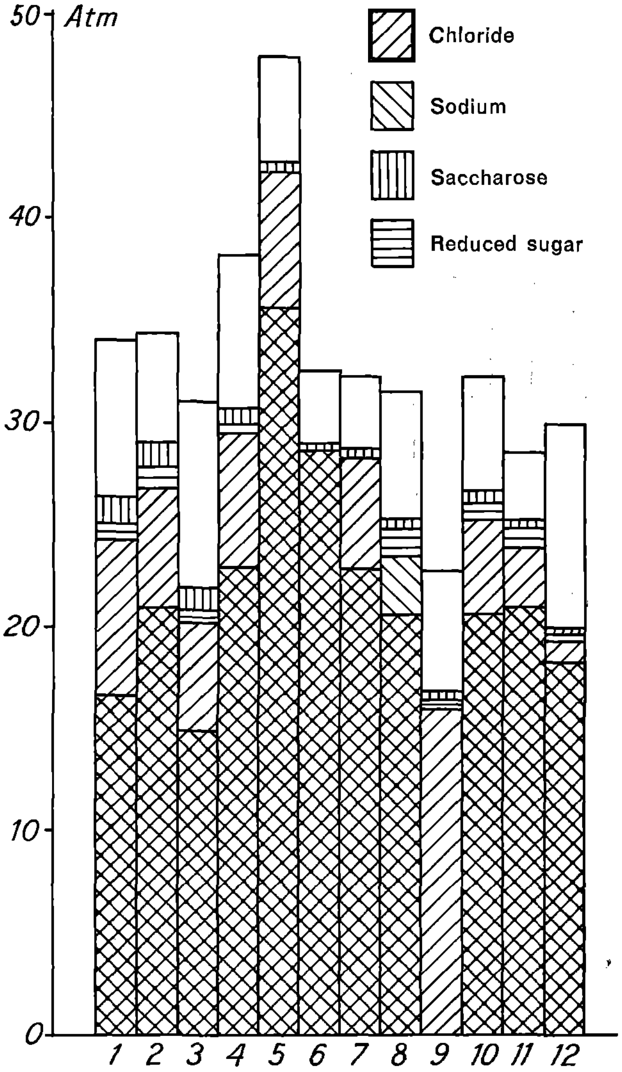

FIG. 1. Osmotic pressure (complete columns) and ingredients of the cell sap of North American salt marsh (after Steiner). 1. *Spartina glabra;* 2. *Sp. patens;* 3. *Distichlis spicata;* 4. *Juncas gerardi;* 5. *Salicornia mucronata;* 6. *S. europaea;* 7. *Plantago decipiens;* 8. *Striplex hastata;* 9. *Aster subulatus* (Na not determined); 10. *Limonium carolianum;* 11. *Suaeda linearis;* 12. *Iva ovaria.*

1. *Excretion-type.* Only a small number of halophytes are able to excrete salts: (a) among the grasses *Spartina, Distichlis, Aeluropus, Diplachne* and others; (b) *Glaux, Armeria, Limonium, Limoniastrum, Frankenia, Cressa cretica* and others; (c) among the woody plants *Tamarix, Avicennia, Aegiceras, Acanthus ilicifolius,* etc. This salt excretion takes place by certain glandular cells. It is an active process (Ruhland).

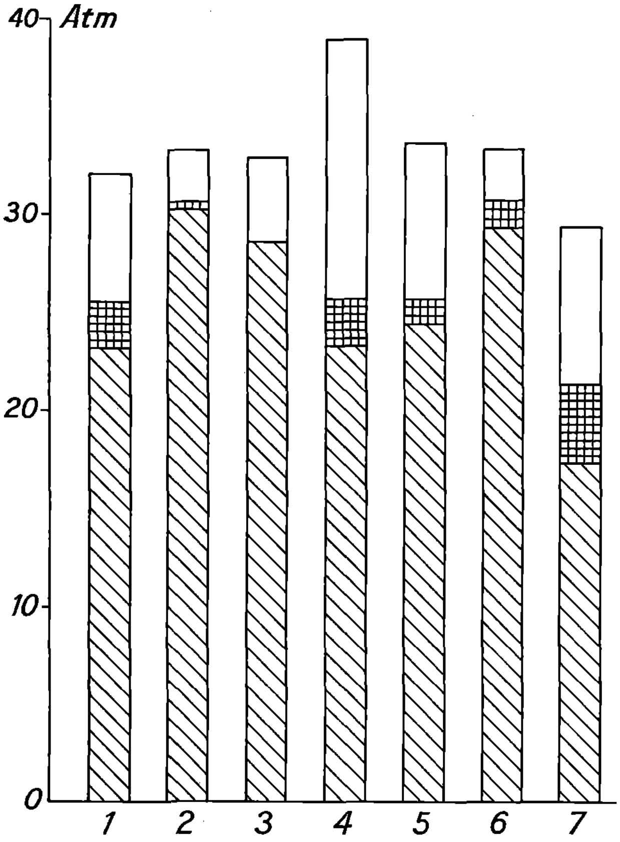

FIG. 2. Osmotic pressure (complete columns), chloride content (obliquely hatched section) and total sugars (cross-hatched section) of East African mangrove plants (after Walter and Steiner).
1. *Sonneratia alba;* 2. *Rhizophora mucronata;* 3. *Ceriops candoliana;* 4. *Avicennia marina;* 5. *Brugniera gymnorrhiza;* 6. *Lumnitzera racemosa;* 7. *Xylocarpus obovatus.*

2. *Regulation-type.* The extreme halophytes like *Salicornia, Arthrocnemum, Halocnemum, Allenrolfea* and others lack the ability to excrete salt. They are very succulent and thwart the rising of the salt concentration by a permanent increase of their water content. Therefore they become more and more succulent during their development. Mangroves, having no salt excretion, do not show such increase of leaf volume with age. In spite of this the salt concentration in the cell sap remains more or less constant. The method of regulation is not known. It may be that a good deal of the salt is transported to the younger growing leaves.
3. *Cumulation-type.* This type lacks any regulatory mechanism. The salt concentration therefore rises more and more during the growing season and, when a certain level is reached, the plant dies. Steiner quotes as an example *Juncus gerardi,* which is a rather salt-tolerant plant (i.e. a facultative halophyte and not an euhalophyte).

The salt accumulation in the cell sap of plants is naturally limited with an increasing concentration of soil solution. We will demonstrate these relations in a more detailed way by following the diagram shown in fig. 4. The sodium chloride content of the soil is shown on the abscissa. The osmotic pressure of the soil solution rises in proportion to it. The upper curve represents the osmotic pressure of the cell sap, and the lower one its chloride content. The hatched area represents non-chlorides in the cell sap (sugars, organic acids and their salts); they are more or less constant.

If the soil contains only traces of salts, the chloride content of the cell sap is relatively high. As long as the salt content of the soil does not increase too much, the halophytes store comparatively more salts in the cell sap. The difference between the osmotic pressure of the cell sap and the osmotic pressure of the soil solution becomes greater, water absorption becomes easier and the development of the plant is furthered. Finally, the optimum is exceeded and the salt accumulation lags behind the increase in the soil salt concentration. When point *K* is reached, the chloride concentration is equal to the osmotic pressure of the soil solution. Water absorption is still possible, but it is more difficult and the growth of the plant is retarded. *M* indicates the point at which the osmotic pressure of the cell sap no longer exceeds that of the soil solution. Water absorption ceases and the plant dies.

Salt storage in halophobic species seems to be different (see fig. 4, dotted line). At the beginning only very few salts are absorbed. But with the increasing salt concentration in the soil the roots are injured, their permeability increases and the salt absorption goes suddenly up so that the plant is killed. The behaviour of facultative halophytes is intermediate (see interrupted line).

There is a peculiarity of the embryo development of halophytes. Although the seeds ripen late in the season, when the plant contains a lot of salts, they are in certain cases free of chlorides (Schratz). The same phenomenon was found with seedlings of the non-viviparous *Avicennia.* Of particular interest, however, is the fact that the seedlings of viviparous mangroves still hanging on the tree not only contain a small amount of chlorides, but their osmotic pressure is even lower than that of the soil solution or of the cell sap of the mother plant. Therefore

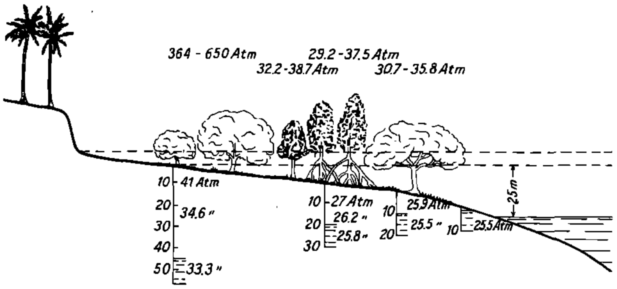

FIG. 3. Schematic profile through the coast mangrove near Tanga (East Africa). Numbers in lower part give the osmotic pressure of soil solution at different depths; in the upper part the extreme osmotic pressure of the individual species.

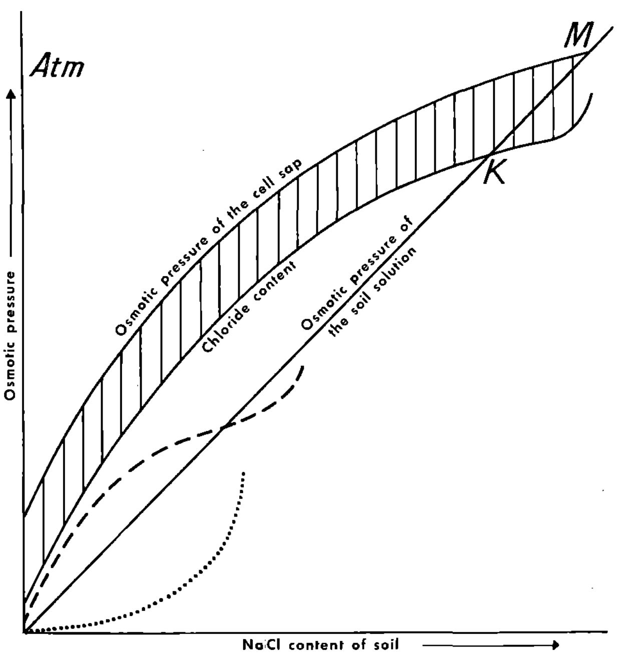

FIG. 4. Relations between sodium chloride of soil and the composition of cell sap.

the seedling cannot absorb the water by normal osmosis, but has to get its water by a glandular activity of the placenta cells.

THE SUCCULENCE OF HALOPHYTES

Most of the halophytes have succulent leaves and stems. The nonhalophytes, too, become more succulent on salt soils. Lesage performed similar experiments with *Lepidium sativum.* Boris Keller had already been able to show that succulence increases with the increasing concentration of the salt solution, but only in the case of chlorides. Sulphates do not produce this effect. Van Eijk has recently confirmed these results, as Table 1 shows.

TABLE 1. Degree of succulence (water content/surface) of *Salicornia* in relation to the concentration of nutrient solution

Conc. (in Mol)	NaCl	KCl	Na_2SO_4	$NaNO_3$	$MgCl_2$	$CaCl_2$
0	33±1	33±1	33±1	33±1	33±1	33±1
1/12	36±1.5	39±1.2	36±0.8	36±1.8	41±1.4	40±1
2/12	39±2.1	39±1.2	—	37±1.7	42±1.4	47±3
4/12	45±1.2	42±1	36±0.3	34±1.2	45±2	—
6/12	43±1.5	43±1.1	—	—	—	—
8/12	51±4	42±1	—	—	—	—

The contrast in the effect of chlorides on the one hand and sulphates and nitrates on the other is very marked, whereas the differences in the effect of diverse cations is not very pronounced. Unfortunately, in no case was the salt concentration in the plant itself determined, although it is responsible alone for the effect on the protoplasm and on the morphological structure of the plant.

The influence of chlorides on the degree of succulence could be regarded as a specific effect of the chlorine-ion. We know that the hydration of proteins is increased by chlorides, and that, on the contrary, it is largely decreased by sulphates. The same effect of increased succulence can also be obtained if the sulphates are accumulated in the cell sap to the same extent as the chlorides. This was not examined in van Eijk's experiment.

Van Eijk rejects the view that there is a relation between increasing succulence and increasing hydration. He remarks that the hydration of proteins is increased to a greater extent by nitrates than by chlorides, although the succulence is not altered. But the nitrates are commonly reduced in the plant to amino-groups and only fairly seldom accumulate in the cell sap as nitrates. Therefore the hydration of the protoplasm can remain unchanged too even if we add a greater amount of nitrates to the nutrient solution.

It is still not possible to get a definite answer to this question. Some observations in the Namib desert seem to confirm the importance of the hydration-effect of chlorides.

CHLORIDE AND SULPHATE HALOPHYTES

The soils of the Namib desert (South-West Africa) contain both chlorides and sulphates. But different plants growing side by side on the same soil do not accumulate in their cell sap those salts in the same proportion. This is clear from Table 2.

TABLE 2

	Zygophyllum stapffii		*Arthraerua leubnitziae*	
	Osm. press.	Chlorides	Osm. press.	Chlorides
	atm.	atm.	atm.	atm.
Summit of Mount Rossing	41.9	33.8	33.2	10.0
A little lower	37.2	32.8	28.9	5.1
Rose Quarcit	34.5	26.2	28.9	8.3
Dry Welwitschia Creek	27.5	22.1	31.2	11.0

Neither of these plants excretes salts. Their osmotic pressure is nearly identical. Yet the chloride content of *Arthraerua* is much lower. At the same time this species, in contrast to *Zygophyllum,* is rather xeromorphic, and not at all succulent. The determination of sulphates in the cell sap showed that the sulphate content of *Zygophyllum stapffii* is very low (0.42–3.15 atm.), while that of *Arthraerua* is always much higher (2.9–6.2 atm.). We may therefore consider the succulent *Zygophyllum* as a halophyte accumulating more chlorides, and the non-succulent *Arthraerua* as a halophyte accumulating many sulphates.

The examination of the cell sap of a greater number of halophytes enables us to formulate some general rules for the halophytes of the Namib desert: (a) Typical succulent halophytes with succulent leaves and stems always have a relation of sulphates to chlorides (the concentrations in atm.) of more than 3 per cent; (b) in hemisucculent halophytes with succulent leaves and woody stems the relation is between 3 per cent and 10 per cent; (c) this relation increases to 10 per cent and, even to more than 60 per cent, in non-succulent and often xeromorphic halophytes, to which *Welwitschia mirabilis* also belongs. But the sum of chlorides and sulphates is always smaller in the last group than in the first, and it is therefore difficult to decide whether the succulence is a specific effect of the chlorine-ions or the result of the higher salt concentration (Arnold)[1].

CONCLUSIONS

A knowledge of their salt economy is necessary for the understanding of the physiology of halophytes. It means that we have to know the amount and the kind of salt stored by the plants in their cell sap. Only these salts and not those in the soil have an effect on the plant protoplasm. The salts in the soil come into contact exclusively with the roots and change the permeability of the root cells. With regard to the salt economy of halophytes certain investigations have been made already. The considerable salt storage compensates the osmotic pressure of the soil solution and so balances the water economy. The protoplasm of halophytes is not sensitive to the toxic effect of the salts. The effect is only a morphological change of the plants, which become more succulent. This is especially the case with those species that store chlorides and not sulphates. The behaviour of non-halophytes is quite different. Nearly all crop plants belong to this group. To them the salts are toxic and are tolerated only in very small amounts.

Hitherto we were mostly content with examining the relations between the salt content of the soil and the development of plants growing on it. But this is insufficient. We can get an understanding of the salt economy of these plants only if we determine the salt concentration in the plants themselves, because only the salts within the plants and stored in their cells have an influence on the protoplasm and its life functions. Therefore the chlorides are especially important, since their intake by the plants is easier than that of sulphates and they do not participate in the metabolism, but are found as free ions in the vacuoles, often in a very high concentration.

Only if we get to know better the salt content of the plants on different salt soils will we be able to provide more precise information on the salt susceptibility and the salt tolerance of the individual species.

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[1] Op. cit.

RÉSUMÉ

L'adaptation des plantes aux sols salins (H. Walter)

Pour comprendre la physiologie des halophytes, il faut connaître l'économie des sels, c'est-à-dire la quantité et la nature des sels emmagasinés dans le suc cellulaire des plantes. Ce sont uniquement ces sels, et non ceux du sol, qui exercent un effet sur le protoplasme des plantes. Les sels que contient le sol ne sont en contact qu'avec les racines et modifient la perméabilité de leurs cellules. On a déjà fait certaines recherches sur l'économie des sels chez les halophytes. La quantité considérable des sels emmagasinés compense la pression osmotique du sol et équilibre ainsi le bilan hydrique. Le protoplasme des halophytes n'est pas sensible aux effets toxiques des sels. Ceux-ci produisent seulement une modification morphologique des plantes, qui deviennent plus succulentes. C'est particulièrement le cas des espèces qui emmagasinent uniquement les chlorures et non les sulfates.

Le comportement des plantes non halophytes est tout à fait différent. Presque toutes les plantes cultivées appartiennent à ce groupe. Les sels exercent sur elles un effet toxique et elles ne peuvent les tolérer qu'à très faible dose.

Jusqu'ici nous avons surtout examiné les rapports entre la teneur en sels du sol et le développement des plantes qui y poussent. Mais cela ne suffit pas. Nous ne pouvons comprendre l'économie hydrique de ces plantes que si nous connaissons la concentration en sels dans les plantes elles-mêmes, car ce sont seulement les sels absorbés par les plantes et emmagasinés dans leurs cellules qui ont un effet sur le protoplasme et sur les fonctions vitales. Les chlorures sont particulièrement importants à cet égard, car les plantes les absorbent plus facilement que les sulfates; en outre, ils ne participent pas au métabolisme, mais se trouvent sous forme d'ions libres dans les vacuoles, souvent avec une concentration très forte.

C'est seulement quand nous connaîtrons mieux la teneur en sels des plantes qui poussent sur différents sols salins que nous parviendrons à préciser la sensibilité ou la tolérance aux sels des différentes espèces végétales.

ESSAI SUR LA VÉGÉTATION HALOPHILE

par

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TOLÉRANCE AUX SELS DE QUELQUES ESPÈCES SPONTANÉES CARACTÉRISTIQUES

La nature des sels contenus dans la terre est, dans la plupart des cas, assez mal connue: on se trouve, le plus souvent, en présence de mélanges dont les pourcentages sont extrêmement variables selon les saisons. Cette diversité n'est guère réalisable dans les essais de laboratoire où le milieu créé artificiellement est toujours beaucoup moins complexe et plus stable.

Cependant, il est admis que le magnésium et le sodium, dont les sels sont les plus courants dans le cas du salant blanc, ont une action à peu près identique: le magnésium est pourtant plus préjudiciable à la végétation que le sodium. Celui-ci intervient en modifiant les propriétés physiques des sols, qui deviennent plus gluants et moins perméables. Il rend ainsi le milieu peu favorable aux pratiques agricoles et au développement des végétaux ou des cultures.

En outre, la salinité provenant de la présence de sulfates est beaucoup plus nuisible que celle qui est due aux chlorures, l'excès de sulfates déterminant une baisse de l'intensité métabolique.

Enfin, dans les solontchaks de la *zone tellienne*, qui reçoivent de 200 à 350 mm de pluie par an, la nappe phréatique, presque toujours saumâtre (8 à 8,5 g de chlorures en NaCl par litre), a toujours un niveau élevé, voisin de la surface du sol.

Le végétal se trouve donc obligé de supporter: *a*) des mélanges de plusieurs sels dont la toxicité est très variable et s'accroît avec sa complexité; *b*) un excès d'eau à concentration saline plus ou moins forte.

Pour toutes ces raisons, il est extrêmement difficile de reproduire dans les essais des conditions analogues à celles qu'on rencontre dans le milieu naturel.

La végétation spontanée, toujours parfaitement adaptée aux conditions locales (si cela n'était, elle ne survivrait pas), peut donner des indications valables sur la salure des sols où elle évolue avec le seul appoint des précipitations atmosphériques qui, dans les pays arides ou subarides, sont rares et non salées.

Elle peut donc servir à reconnaître la valeur agricole des terrains et à préciser la résistance aux sels des espèces spontanées d'abord, puis cultivées.

Lorsque les sols sont recouverts en permanence par une croûte saline, dont l'épaisseur peut atteindre parfois plusieurs centimètres (sebkhas du Sahara central), aucune végétation ne parvient à s'installer. C'est alors la stérilité absolue.

Il en est généralement de même lorsque des efflorescences salines se manifestent pendant la saison sèche (juillet à septembre). Les terrains renferment alors des quantités de sels assez importantes, qui ne permettent à aucun végétal de se développer.

Ces cas sont extrêmes. Pourtant, ils intéressent plusieurs milliers d'hectares: chotts, sebkhas. Les teneurs en sels, toujours considérables, sont très variables: 50 à 200 g de chlorures en NaCl par kilogramme de terre sèche dans l'horizon normalement visité par les racines nourricières des plantes.

Quand l'une des espèces indiquées ci-dessous peut être considérée comme dominante (pousse en abondance), la salinité est:

1. Trop forte pour que la mise en culture soit possible:
   a) dans les solontchaks humides de la zone tellienne (plaines sublittorales d'Oranie): *Halopeplis amplexicaulis* (Vahl.) Boiss., qui pousse sur le rivage des sebkhas (Ben Ziane, Oran), en limite de la zone stérile, dans des terrains renfermant plus de 20 g de chlorures par kilogramme de terre sèche; *Arthrocnemum glaucum* (Del.) Ung. et Stern, qui caractérise les milieux salés instables (inondations, apports alluvionnaires); la teneur en sels varie de 10 à 15 g de chlorures par kilogramme de terre sèche; pour parvenir à se maintenir, cette espèce est presque toujours installée sur des coussinets qui, dans les zones les moins stables, atteignent 1 mètre de hauteur (zone de divagation de l'Oued Tinn dans la plaine des Bordjias); *Salicornia fruticosa* L., qui vit dans les stations stabilisées, hu-

mides et salées: 7 à 12 g de chlorures par kilogramme de terre sèche; *Salicornia herbacea* L.: cette Salsolacée assez rare dans les solontchaks humides de plaines sublittorales d'Oranie (lac d'Hammam Salama, partie occidentale de la sebkha d'Oran) s'avance au-delà des pionniers de l'*Arthrocnemum* car elle se développe pendant la période d'exondation dans les milieux très humides; *Mesembryanthemum nodiflorum* L., qui croît dans les sols secs, quelque peu gypseux; *Limonium delicatulum* (de Gir.) O. K., qui affectionne les milieux gypso-salins; *Frankenia pulverulenta* L., qui est localisée dans les solontchaks humides riches en gypse; *Spergularia salina* (Presl.) Dietr., qui traduit une dominance des sels magnésiens; *Cressa cretica* L. et *Juncus subulatus* Forsk., qui caractérisent les solontchaks très humides et salés (8 à 12 g de chlorures), susceptibles d'être inondés pendant les mois d'hiver; *b*) dans les solontchaks humides des hautes plaines steppiques: *Halocnemum strobilaceum* (Pall.) M. Bieb, qui vit sur des coussinets parfois énormes, dans les solontchaks gypso-salins des rivages des chotts (Chott ech Chergui: région de Spissifa); *Salsola vermiculata* L., qui est installée dans les terrains secs et salés de la bordure des chotts.

2. Assez forte pour imposer l'aménagement d'un réseau de drains, la réalisation d'irrigation de lessivage et l'application de techniques culturales particulières: culture sur billons plats ou sur bourrelets, paillage, etc.: *a*) dans les solontchaks humides de la région tellienne (plaines sublittorales d'Oranie): *Suaeda fruticosa* (L.) Forsk.; *Atriplex hastata* L.; *Atriplex halimus* L.; *b*) dans les solontchaks humides des hautes plaines steppiques: *Suaeda fruticosa* (L.) Forsk.; *Atriplex mauritanica* Boiss. et Reut.; *c*) dans les solontchaks secs des vallées sahariennes (vallée de la Saoura dans le Sahara occidental): *Salsola vermiculata* L. var. *villosa* (Del.) Moq.; *Salsola foetida* Del. var. *eu-foetida* Maire; *Suaeda monodiana* Maire; *Suaeda mollis* (Desf.) Del.; *Traganum nudatum* Del.

La plupart des espèces spontanées tolérantes au salant appartiennent à la famille des Salsolacées.

Les types de végétation qu'elles constituent (landes à soudes dans le Tell, déserts à Salsolacées au Sahara) se rencontrent partout sous les climats arides ou subarides.

Cependant, il convient de remarquer que:

1. Les halophytes, malgré leur parfaite adaptation, absorbent moins d'eau au contact d'une solution saline qu'en présence d'une solution non salée.

   Il s'ensuit que ces plantes sont souvent sujettes à une déshydratation physiologique dont l'amplitude est fonction de la concentration en sels.

   Pour les espèces de la famille des Salsolacées, elle se traduit, dans les solontchaks humides du Tell, par les accidents temporaires suivants: *a*) jaunissement des feuilles, puis des pousses nouvelles non lignifiées; *b*) diminution de la longueur des feuilles qui s'épaississent; *c*) jaunissement et réduction simultanés de la taille des feuilles; pousses annuelles chlorotiques et très réduites; rubéfaction de tout le végétal.

2. Les faibles teneurs en sels influent favorablement sur le développement des halophytes tandis qu'un excès amène une dépression qui peut provoquer: *a*) un ralentissement de la germination en raison de la lenteur d'absorption de l'eau; *b*) un retard dans la croissance des végétaux qui peut même s'arrêter définitivement: nanisme; *c*) une fructification hâtive et peu abondante, malgré une floraison souvent très abondante; *d*) dans les cas extrêmes, la plante meurt avant d'avoir pu se reproduire.

   Ces accidents sont d'ailleurs dus davantage à la sécheresse physiologique qu'à une absorption excessive de sels.

3. Sur les solontchaks de la région tellienne, les halophytes trouvent toujours un régime hydrique favorable grâce à la proximité des eaux phréatiques et à l'humidité constante du sous-sol.

   Dans les solonetz au contraire, seuls les halophytes à enracinement profond peuvent se maintenir car ils ont la possibilité d'aller chercher l'eau à de grandes profondeurs.

4. Le mode d'adaptation au salant des halophytes n'est pas identique. La résistance peut être obtenue: *a*) par accumulation de grandes quantités de sels dans les tissus (*Salicornia, Halopeplis*); *b*) par élimination des sels absorbés en excès (*Limonium*); *c*) par la faculté de n'absorber que les quantités de sels supportées par le végétal.

Outre les Salsolacées, une espèce arbustive offre un certain intérêt pour la reconnaissance du salant en zone aride, subaride ou saharienne: c'est le Tamarix.

Quatre espèces, en effet, sont nettement localisées: *a*) dans les solontchaks sodo-calciques stables: *Tamarix africana* Poiret.; *b*) dans les alluvions peu salées et humides (berges et lits majeurs des oueds): *Tamarix gallica* L.; *c*) dans les solontchaks humides des hautes plaines steppiques sur le rivage des chotts et des sebkhas: *Tamarix Bounopaea* J. Gay; *d*) dans les alluvions salées du Sahara: *Tamarix pauciovulata* J. Gay.

Comme pour les Salsolacées, les variations de la concentration saline déterminent une sécheresse physiologique qui se traduit par les accidents suivants: *a*) changement de la coloration du feuillage: couleur bleutée pour le *Tamarix gallica* ssp. *nilotica* dans les solontchaks humides de la station d'étude des sols salins d'Hamadena; *b*) chute des feuilles à l'extrémité des rameaux.

MODIFICATION DU MILIEU NATUREL PAR LES IRRIGATIONS

Les arrosages ont toujours une influence importante sur la végétation halophile, qui évolue normalement avec le seul appoint des précipitations atmosphériques. Leur action est particulièrement caractéristique dans les solontchaks de la région saharienne.

Les expériences ont été réalisées: *a*) de 1948 à 1952 dans les solontchaks des plaines sublittorales d'Oranie; *b*) de 1954 à 1958 dans les solontchaks du Sahara occidental.

Influence des arrosages effectués avec de l'eau douce

Les essais ont été réalisés dans les solontchaks de la plaine de l'Habra, à sol argileux, relativement perméables.

Les apports d'eau (4000 à 6000 m³/ha répartis en 4 à 5 arrosages) ont provoqué une poussée vigoureuse de la végétation. L'aspect des plantes a changé: élargissement des feuilles, allongement des rameaux, coloration verte plus accentuée, etc.

En outre, dans le *Suaedetum,* ces irrigations ont favorisé le développement des espèces annuelles intercalaires (Graminées et surtout Légumineuses) engendrant une végétation appelée parfois prairie à Papilionacées.

Dans les solontchaks sodo-calciques humides, renfermant de 3 à 10 g de chlorures par kilogramme de terre sèche, et à sous-sol perméable (horizon de sable boulant, jaune, très filtrant à un mètre de profondeur), des arrosages hivernaux (4 à 5) effectués avec des eaux titrant 0,5 g de chlorures en NaCl par litre, ont amené la disparition de la lande à soudes (*Suaedetum*), qui a été remplacée par une prairie à fétuques (*Festucetum*). Ce groupement végétal comprend de nombreuses espèces fourragères, notamment: *Festuca elatior* L. ssp. *arundinacea* (Schreb) Hack., *Hordeum maritimum* With., *Trifolium resupinatum* L., *Trifolium maritimum* Huds., *Melilotus messanensis* (L.) All., *Melilotus sulcata* Desf., *Medicago ciliaris* (L.) Krocher, *Medicago hispida Gaertn.* var. *lappacea* (Dur.) Burnat, *Phalaris paradoxa* L.

Les irrigations, consommant 1200 m³ environ, ont été faites d'octobre à fin janvier en utilisant la submersion dirigée. Les planches mesuraient 50 m de largeur sur 75 à 100 m de longueur.

Aucun drainage n'avait été effectué. Seuls, quelques travaux de nivellement avaient été réalisés pour faciliter la circulation de l'eau.

Des apports d'eau supplémentaires (3000 m³/ha environ) ont désorganisé le groupement à *Festuca arundinacea,* qui a fait place à un peuplement presque pur de *Juncus subulatus* Forsk. et de *Juncus maritimus* Lam., beaucoup plus hydrophile mais susceptible de tolérer des teneurs en sels voisines de 10 g (en NaCl par litre) dans les eaux de submersion.

L'arrêt des arrosages a entraîné la disparition du *Festucetum* et le peuplement de *Suaeda fruticosa* (L.) Forsk. s'est installé à nouveau en une seule campagne, ce qui montre sa parfaite adaptation aux conditions locales (solontchaks sodo-calciques renfermant 3 à 10 g de chlorures en NaCl par kilogramme de terre sèche, faible pluviométrie: 300 mm par an). Cette transformation de la lande à soudes en prairie à fétuques n'a jamais pu être obtenue dans les solontchaks sodo-calciques, à sous-sol imperméable de la station d'étude des sols salins d'Hamadena dans la plaine du Bas-Chéliff.

Malgré un nivellement parfait (destruction des coussinets de *Suaeda*), les essais entrepris au cours de la campagne 1951–1952 ont déterminé l'installation d'un peuplement de *Salicornia fruticosa* L. Ce groupement hyperhalophile ne présentant aucun intérêt agricole (c'est un très mauvais groupement en raison de la rareté des compagnes), l'expérience, qui consommait beaucoup moins d'eau (3500 m³/ha environ), a été abandonnée.

Influence des arrosages effectués avec des eaux saumâtres

L'irrigation avec des eaux saumâtres a été réalisée dans les solontchaks relativement perméables des centres d'étude d'irrigation d'Igli et d'Adrar dans le Sahara occidental.

Dans cette région, l'eau douce fait défaut et les précipitations atmosphériques sont extrêmement rares. Les eaux phréatiques, qui sont toujours chargées, sont utilisées pour les irrigations.

A Igli, sur solontchak sec (désert à Salsolacées), les irrigations sont faites avec des eaux provenant de l'inféroflux de la Saoura. Elles titrent de 3 à 6 g en NaCl par litre selon les saisons.

Les arrosages (10000 m³/ha par an) ont déterminé l'apparition et l'installation des halophiles grasses, caractéristiques des solontchaks humides de la région tellienne.

Le processus de leur établissement a été le suivant: En 1954, défrichement du désert à Salsolacées: groupement à *Salsola vermiculata* L. var. *villosa* (Del.) Moq. et *Salsola foetida* Del. var. *eu-foetida* Maire, mise en culture. En 1955, mise en culture. En 1956, apparition: 1° des halophiles grasses, inconnues jusqu'alors dans cette vallée saharienne: *Suaeda fruticosa* (L.) Forsk. var. *longifolia* (Koch) Fenzl., *Frankenia pulverulenta* L., *Spergularia salina* J. et C. Presl. et *Cynanchum acutum* L.; 2° des compagnes spécialisées du groupement à *Suaeda fruticosa: Sphenopus divaricatus* (Gouan.) Rchb., *Pholiurus incurvus* (L.) Schinz et Thell ssp. *incurvatus* (L.) Maire, *Melilotus indica* (L.) All. et *Ormenis praecox* (Link.) Briq. En 1957, apparition de *Phragmites communis* Trin. var. *isiacus* (Del.) Coss. et Dur. En 1958, apparition de *Juncus subulatus* Forsk. et *Aeluropus littoralis* (Gouan.) Parl. var. *repens* (Desf.) Coss. et Dur.

Les espèces du groupement primitif se maintiennent çà et là. Mais leur végétation est diminuée, en raison de l'humidité excessive consécutive aux arrosages.

Dès que les irrigations ont cessé, les halophiles grasses disparaissent en quelques mois et les espèces du désert à Salsolacées se réinstallent.

Ces essais ont été réalisés sur des planches mesurant 8 m de largeur sur 25 m de longueur. L'irrigation était assurée par submersion dirigée.

A Adrar, les irrigations ont été effectuées dans des conditions semblables (submersion dirigée sur planches de 8 m de largeur sur 25 m de longueur; volume 16000 m³/ha par campagne répartis en 14 à 15 irrigations).

Les eaux titraient 3 g de chlorures en NaCl par litre.

Les arrosages ont déterminé l'apparition des halophiles demi-grasses, caractéristiques du désert à Salsolacées et de quelques spécimens d'halophiles grasses spécifiques des solontchaks humides.

Leur installation s'est faite dans les conditions suivantes: En 1954, destruction du peuplement de *Zygophyllum album* L., qui occupait le solontchak inerte. En 1955, aménagement du centre d'étude d'irrigation, mise en culture. En 1956, mise en culture. En 1957, apparition de *Salsola vermiculata* L. var. *villosa* (Del.) Moq., *Salsola foetida* Del. var. *eu-foetida* Maire, *Frankenia pulverulenta* L., *Sphenopus divaricatus* (Gouan.) Rchb. et *Suaeda fruticosa* (L.) Forsk. var. *longifolia* (Koch) Fenzl. En 1958, apparition de *Spergularia salina* J. et C. Presl. et *Atriplex dimorphostagia* Kar. et Kir.

Dès que les arrosages sont arrêtés, toutes ces espèces disparaissent en moins de trois mois. Seul, *Zygophyllum album* L. se maintient et pullule grâce à l'humidité. On peut penser que les espèces qui sont apparues au Sahara ont été apportées par les oiseaux, ou par les crues de la Saoura.

SUMMARY

An experiment on halophilous vegetation (P. Simonneau)

Spontaneous vegetation is always perfectly adapted to local conditions; otherwise it would not survive. It can therefore provide useful pointers to the value of saline soils.

When an area is covered with crystalline crusts (sebkhas) or saline efflorescences at the end of summer, no vegetation can gain a hold.

Salinity is too strong for the growing of crops to be possible when the soil cover comprises *Halopeplis amplexicaulis, Arthrocnemum glaucum, Salicornia fruticosa, S. herbacea,* etc., in the humid solonchaks of the sublittoral plains of Oran (300 mm. of rainfall per year) or *Halocnemum strobilaceum* in the solonchaks of the high steppe-like plains (200 mm. of rainfall per year).

Salinity can be effectively controlled (drainage, leaching irrigation, special cultivation techniques, etc.) in the humid solonchaks of the sub-littoral plains, where the principal species are *Suaeda fruticosa, Atriplex hastata, A. halimus*; in the solonchaks of the high steppe plains where *Suaeda fruticosa* and *Atriplex mauritanica* are found; and in the dry solonchaks of the Saharan valleys, where the principal species are *Salsola vermiculata, S. foetida, Suaeda mollis, S. monodiana,* etc.

In addition to these halophytes, which are typical of the saline areas of Algeria and the Sahara, the various species of *Tamarix* can give a fairly accurate idea of the salinity of the environment.

Watering always has a significant influence on vegetation in arid or sub-arid climates.

In the humid solonchaks of the Habra plain, with permeable sub-soil, 4,000–6,000 m.^{3}/ha. (water with 0.50 gm. of chloride in the form of NaCl/l.) suffice to do away with the Saltwort (*Suaedetum*) "lande". It is replaced by Fescue (*Festucetum*) grassland, affording relatively good pasturage.

In the solonchaks of the western Sahara, 10,000 m.^{3}/ha. (3–6 gm. of chloride in the form of NaCl/l.) will drive out the species of the *Salsola* desert, when the hyperhalophiles of the humid solontchaks of the Tell take their place. After three irrigation campaigns, some halophytes *Phragmites communis, Juncus subulatus* and *Aeluropus littoralis* may appear.

Finally, at Adrar in the central Sahara, 16,000 m.^{3}/ha. will bring about the installation of the *Salsola* desert species and a few fleshy halophiles (*Suaeda fruticosa*) on the inert solonchaks originally occupied by a *Zygophyllum album* population.

LES PEUPLEMENTS D'"AVICENNIA" DES CÔTES SUD DE L'IRAN

par
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Les terres marécageuses des côtes du sud de l'Iran et des îles du golfe d'Oman sont occupées par des peuplements d'*Avicennia* qui s'étendent de la frontière de l'Irak jusqu'au Pakistan.

Ces peuplements ne sont pas continus, mais sont plutôt disséminés sur des espaces plus ou moins étendus, dont les plus anciens sont clairsemés tandis que les plus récents sont plus vastes et mieux peuplés.

ZONES DE CROISSANCE

Ces peuplements sont situés dans trois zones:

1. *Golfe Persique.* Entre la frontière de l'Irak et Bendere-Lengueh existaient autrefois de vastes peuplements, mais malheureusement il n'en subsiste aujourd'hui que sur une superficie de 24 hectares dans le golfe de Nabend.
2. *Détroit d'Hormouze.* Entre Lengueh et l'embouchure du Gabrigue (50 km à l'est de Djask), on trouve les plus importants peuplements de palétuviers, particulièrement sur les côtes de l'île de Gueshm (2400 ha), à Khamir, à l'embouchure du Mehran (425 ha), à Novsaze (2000 ha) et entre Ras-Djaghine et l'embouchure du Gabrigue (2000 ha).
3. *Région de Tchah Bahar,* 500 ha.

Au total, ces peuplements couvrent une superficie d'environ 7500 ha.

CARACTÉRISTIQUES

L'*Avicennia* de l'Iran est l'*Avicennia officinalis.* Les feuilles sont coriaces, longues de 6 à 7 cm et larges de 2 cm. Les fleurs apparaissent vers la fin de mars et durent parfois jusqu'au mois de juin. La fructification est abondante.

Cet arbre aime la lumière et peut vivre jusqu'à cent ans et parfois même plus.

Sa croissance est lente mais régulière; les arbres de 20 cm de diamètre peuvent être âgés de soixante à soixante-dix ans.

Le tronc n'est pas droit; il peut atteindre 5 à 7 mètres et avoir, à hauteur de poitrine, 35 à 40 cm de diamètre. Quelques arbres atteignent 10 mètres avec un diamètre de 45 cm.

La couronne est grande et les racines superficielles produisent d'abondants pneumatophores. L'*Avicennia* ne rejette pas de nouvelles branches.

UTILISATION

Les feuilles d'*Avicennia* servent à l'alimentation des chameaux. Parfois les bêtes vivent en liberté dans les peuplements et, de ce fait, causent d'importants dégâts en mangeant, à marée basse, les fruits et les graines des arbres.

Les feuilles ramassées par les indigènes servent à l'alimentation des bestiaux car, le plus souvent, ceux-ci ne peuvent pas pénétrer dans ces régions marécageuses et atteindre directement les arbres.

Le bois d'*Avicennia* sert pour le chauffage; mais pour cet usage les indigènes préfèrent plutôt le bois du *Prosopis spicigera,* du *Zizyphus* et du *Tamarix,* tandis que les matelots arabes qui viennent des îles du golfe Persique et de la mer d'Oman emportent les feuilles et les branches, causant ainsi de grands dégâts.

ÉCOLOGIE

L'*Avicennia* pousse dans les marécages des régions chaudes où les eaux sont salées ou saumâtres. La boue noirâtre est profonde et l'on s'y enfonce parfois jusqu'au genou: dans de tels lieux les peuplements ont été moins saccagés.

Le sable empêche le développement de l'arbre et, là où les dunes avancent, les peuplements d'*Avicennia* ont graduellement dépéri.

LE PALÉTUVIER

Depuis près de trente ans, plusieurs tentatives ont été faites pour introduire et acclimater le palétuvier en Iran; les plants ont été importés de Zanzibar.

Il existe un petit peuplement de 2 ha environ sur les côtes du golfe d'Oman; il est pur, homogène et dense. Aux alentours de cette petite forêt, dans les peuplements d'*Avicennia,* on trouve des pieds de Rhizophores âgés de un à douze ans. Cet arbre fructifie vers quinze ans et les hypocotyles d'une vingtaine de centimètres se trouvent non seulement au pied de l'arbre, mais la marée les transporte parfois jusqu'à 3,5 km de distance et, de cette façon, la forêt hétérogène d'*Avicennia* se mélange graduellement avec le palétuvier qui semble être le *Rhizophora mucronata.*

LES PLANTES DES ENVIRONS DE MASSILEH ET LES MODIFICATIONS DE LEUR STRUCTURE INTERNE

par

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Les déserts salés de Massileh occupent une grande partie des grands déserts du nord de l'Iran. Ils sont limités à l'est, au nord-est et au sud-est par les déserts de Garmsar et de Dacht Kevir. Aux environs de Massileh on rencontre des terrains couverts de sel, ayant une structure spéciale. Au centre de cet affaissement on observe des hauteurs ayant l'apparence de dunes désertiques. Ces éminences, surtout celles du sud et de l'est, sont des milieux propices au développement d'une flore spéciale. Ces plantes sont adaptées aux diverses conditions ambiantes et, dans chacune de ces localités, on trouve une végétation spécifique.

Les hauteurs aux alentours de Massileh, où les eaux courantes et parfois torrentielles ont creusé des ravins et des lits de charriage, ont formé dans certaines parties des cônes de déjection contenant encore une certaine quantité de sel. La salinité de ces dernières parties est moindre, car les eaux superficielles ont dissous une grande partie des sels qui existaient originairement dans le sol. Les conditions de croissance d'une certaine végétation y sont développées. On y rencontre parfois des plantes n'ayant aucun rapport avec la végétation des terrains salés.

Nous avons pu pénétrer au cœur de ces parages salés pour atteindre ces hauteurs et les lieux moins salés, pour y récolter des spécimens de diverses plantes, afin de les étudier convenablement et les collectionner.

Après avoir déterminé un certain nombre de ces plantes, nous sommes arrivés à les classer en plusieurs groupes distincts.

Les plantes qui poussent dans les sols entièrement salés, c'est-à-dire dans les sols spongieux couverts d'une croûte blanchâtre et crevassée, composée de différents sels, sont peu variées et leur nombre diminue à mesure qu'on avance vers le centre. Après quelques centaines et parfois quelques dizaines de mètres, cette végétation disparaît complètement. On ne rencontre plus une seule plante.

La végétation des parties moins salées présente un aspect spécifique qui change avec le degré de salinité. Dans ces *kevirs,* si l'on retire la partie superficielle qui, imprégnée de sels, s'est transformée en une croûte résistante, on aperçoit toujours un sol humide et, dans les parties un peu plus profondes, on rencontre toujours de la boue mélangée aux différents sels:

1. Les plantes qu'on trouve dans les terres propices de ces *kevirs* et dans les steppes environnantes sont: *Salicornia herbacea* L. (Mobarakieh, près de Veramine); *Salsola subaphylla* Moq. (près de Sefidab); *Seidlitzia rosmarinus* (Ehrenb.) Bge. (Mobarakieh); *Artemisia cina* Berge et Schmidt (Mobarakieh, Siah Kouh et Band Ali Khan); *Holocnemum strobilaceum* (Pall.) Moq. (Band Ali Khan).
2. Les plantes rencontrées aux bordures sud de Messile entre Aran et Marandjab sont: *Aristida plumosa* L., *Aristida pennata* Trin. et *Aristida pungens* Deaf.[1]; *Convolvulus eremophilus* Boiss. et Buhse; *Halophyllum robustum* Bge.
3. Les plantes des régions semi-arides (bordures du Kevir). Au cours de nos recherches nous avons pu trouver un certain nombre de plantes appartenant aux différents groupes suivants: *Pteropyrum ancheri* Jaub et sp. (Siah Kouh, Band Ali Khan et Gheiloghe); *Salsola arbuscula* Pall. (entre Sefidab et Band Ali Khan); *Calligonum cosmosum* (environs de Sefidab et à Band Ali Khan); *Bromus macrostachys* Desf. (abords de Houz Soltan); *Glaucium vitellinum* Boiss. et Buhse (Houz Soltan jusqu'au Bagher Abad); *Nardurus orientalis* Boiss. (Houz Soltan; route de Ghom); *Galium setaceum* Lam. (Houz Soltan); *Salsola suriculata* Moq. (BoBraran; nord de Messile); *Stellera lassertii* Wikstr. (Houz Soltan); *Buhsea coluteoïdes* Boiss. (Pol. Dallak; sud de Messile; Houz Soltan); *Torularia tortulosa* (Deaf) O. F. Schultz (Band Ali Khan; Deyr); *Noaea mucromata* (Forsk.) Ascher et Schweinf. (Band Ali Khan; Deyr); *Leptaleum filifolium* (Willd) D. C. (Band Ali Khan; Deyr); *Ephedra distachya* L. (envi-

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[1] Les plantes de ce groupe sont caractéristiques des régions salines et on les a trouvées dans les terres salines de la plupart des régions arides.

rons de Siah Kouh); *Arnebia linifolia* D. C. (Band Ali Khan; Deyr); *Roemeria hybrida* (L.) D. C. (Penlis; nord de Siah Kouh; terrains lavés); *Mathiola chenopodifolia* F. et M. (entre Band Ali Khan et Sefidab).

4. Les plantes récoltées sur les pentes des montagnes surplombant le *kevir*: *Celsia intricata* Bth.; *Glaucium flavum* Crautz.; *Amygdalus spartoïdes* sp. (pente de Sefidab); *Salsola glauca* M. B.; *Calligonum cosmosum* L'Her. (monticules de Molla Sadra, au sud de Sefidab); *Acanthophyllum squarosum* Boiss.; *Achillea talagonica* Boiss.; *Celsia intricata* Bth.; *Brassica deflexa* Boiss. (nord du Pol Dallak); *Lycium turcomanicum* Turez. (pente de Siah Kouh).

Il y a quelque temps, des botanistes étrangers ont visité une partie des régions arides de l'Iran et mentionné un certain nombre de plantes qu'ils ont trouvées sur leur passage. Ces plantes sont:

Aellenia subaphylla (C. A. Mey) Aellen [*Salsola subaphylla* C. A. Mey]; ssp. *en-subaphylla* Aellen [*S. subaphylla* ssp. Typica Iljin] (mer de Sel: nord de Sia Kouh, est de Marandjab); ssp. *Charifii* Aellen (entre la mer de Sel et Sia Kouh; ssp. *Sabetii* Aellen (steppes salées de *kevir*, à 88 km à l'est de Téhéran); *Aellenia glauca* (M. B.) Aellen [*Salsola glauca* M. B.]; ssp. *Vestita* Aellen (steppes salées de la mer de Sel); var. *Glabra* Aellen (près de la mer de Sel); ssp. *Cinerascens* (Moq.) Aellen [*S. glabra V. Cinerascens* Moq.] (Dacht; Kevir); var. *en-cinerascens* Aellen (Sia Kouh; Khar); var. *brachyphylla* (Boiss. et Hauskn.) Aellen [*Salsola brachyphylla* Boiss. et Hauskn.] (bord de Houz Soltan); *Horaninowa aptera* Charif et Aellen (entre la mer de Sel et Sia Kouh); *Haraninowa platyptera* Charif et Aellen (entre la mer de Sel et Sia Kouh); *Cornulaca leucantha* Charif et Aellen [*Cancheri Bunge*] (Sia Kouh; au sud de la mer de Sel; au sud-est de la mer de Sel; à 15 km de Marandjab; entre Kachan et Aran); *Cornulaca monacantha* Delile (sud de la mer de Sel); *Atriplex talarica* (mer de Sel); var. *discolor* (K. Koch) Gaub (Roud Chour); *Autochlamys rechingeri* Delile (au sud de la mer de Sel); *Polygonum argyrocoleon* Steud. (Garmsar).

On a mentionné aussi les plantes suivantes aux environs de Kachan, au bord du Kevir: *Atriplex micrautha* C. A. Mey; var. *typica* Aellen (Kachan); f. *genuina* Aellen; *Chenopodium opulifolium* Schrad (Kachan); *Chenopodium murale* L. (Kachan); ssp. *en-murale* Aellen; var. *genuinum* (Br.); f. *alvescens* (Moq.) Aellen.

L'influence du milieu et du climat sur les plantes poussant aux environs du Kevir (Massileh) et dans les différentes parties surélevées de l'intérieur nous a conduits à procéder à une étude un peu plus approfondie. Nous avons fait des récoltes successives d'une seule espèce dans les différentes localités et pendant les différentes saisons.

Nous avons pu noter les différences de leur structure externe et interne. Nous avons recueilli en premier lieu des échantillons des plantes qui croissent immédiatement auprès des terres salées et couvertes de croûte de sel et, graduellement, nous nous sommes éloignés de ces bordures en nous élevant sur les hauteurs pour observer sur les coupes des différentes parties de ces plantes les changements qui s'y produisent. Cette méthode nous a permis de constater les modifications profondes qui se manifestent dans la structure interne de ces plantes suivant l'éloignement ou la proximite des couches de sel, le degré d'humidité du sol, etc.

Nous avons pris comme échantillons les plantes suivantes: *Seidlitzia rosmarinus* (Ehrenb.) Bge. et *Noaea mucronata* (Forsk.) Ascher et Schweinf.

La première pousse dans les steppes imprégnées de sel avoisinant les terres couvertes de sel, et parfois dans les parties non salées ou au fond des ravins descendant des hauteurs environnantes et dont le sol a été lavé et dessalé.

1. La coupe transversale de la tige de *Seidlitzia rosmarinus*, prise dans le spécimen récolté le 1^er^ février 1958 aux environs de Mobarakieh, montre un parenchyme cortical présentant de grandes cellules non comprimées; ces cellules contiennent un grand nombre de cristaux de sel et de macles; on n'a pas trouvé ces cristaux dans le cylindre central de la plupart des nombreuses coupes.

   La coupe transversale de la tige de cette même plante, récoltée dans les terrains des deux rives de Roud Chour, dans les parties humides, pendant le mois de mars, montre que: le parenchyme cortical est comprimé; les cellules de ce parenchyme ne contiennent pas ou peu de cristaux de sel et de macles; le cylindre central contient un grand nombre de ces cristaux et on y observe nettement l'émigration de ces cristaux de l'extérieur vers l'intérieur.

2. La coupe transversale de la tige de *Noaea mucronata* récolté à Band Ali Khan (région désertique) montre que: l'épiderme est couvert de cils innombrables; les tissus de soutien sont denses; toutes les parties de la tige contiennent des cristaux et des macles en grand nombre.

   Cette même plante, récoltée dans les régions non salées, est dépourvue de ces macles.

Après avoir étudié une série de coupes de ces différentes plantes récoltées en divers endroits, nous pouvons conclure que:

L'augmentation de l'humidité du sol et la grande quantité d'eau absorbée par la racine en dissolvant les sels font que ceux-ci sont entraînés dans le parenchyme cortical. Mais, avec l'abaissement de l'humidité et l'apparition de la sécheresse du sol, ces sels s'accumulent dans le cylindre central pour en augmenter la solidité et remplacer les tissus ligneux de soutien qui ne peuvent apparaître en raison du manque d'eau.

La rigidité de la tige de ces plantes est augmentée par l'accumulation des sels dans le cylindre central.

SUMMARY

The plants in the neighbourhood of Massileh and the changes in their internal structure (H. Golegolabe and A. Zargari)

The paper presents results of a vegetation survey in the salt desert of Massileh, including classification according to salt content of the soil. The second part of the paper presents a more detailed analysis of the histological and physiological effects of salt content on plant growth.

DISCUSSION

A. Hafiz. The author has stated that he has found certain characteristics in the sections of the plants collected from the saline soils. Are these characteristics invariably found in all the plants collected from saline soils?

H. Golegolabe. Nous avons constaté des changements surtout dans les plantes de la famille des Salsolacées et des Polygonacées et nous espérons étendre nos recherches aux autres groupes, et particulièrement à ceux des Cucurbitacées et des Chénopodiacées.

PHYSIOLOGY OF PLANTS CONSUMING SALINE WATER

by

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The possibility of using saline underground waters for irrigation is very limited because these waters contain a considerable amount of harmful salts. The applicability of subsoil and drainage waters to irrigation is, first of all, dependent upon the concentration and composition of salts dissolved therein, and upon the degree to which plants are salt-resistant. It is therefore natural that the problem of utilizing saline waters involves the problem of salt resistance of plants; the latter's main point being the essence of the process of plant adaptation to soil salinization.

The adaptation of plants to salinization of the substratum takes place during their individual development. The intensity and the rapidity of this development are connected with the evolutional history of a given species. The plants most adaptable to a high salt content of the substratum are those which grow in salt-impregnated areas—the halophytes.

Many glycophytes, in which group all cultivated plants are classified, can also, to a certain degree, adapt themselves to salinization, but this degree is much less than in the case of halophytes. Adaptation of glycophytes to salinization is possible mainly because of the changeability of their metabolism and the colloidal and chemical properties of the protoplasm. It should be emphasized immediately that reactions of adaptation are specific in each particular case, according to the quality of the salinization. In natural environments there usually exist chloride and sulphate types of salinization as well as a mixed sulphate and chloride type with domination of chlorides and a chloride and sulphate type with domination of sulphates. The influence of these salinization types has been studied far more than that of carbonate salinization, which sometimes can be found in nature.

In the case of the chloride salinization type, the intensity of metabolism is decreased and it becomes more balanced as regards high salt contents. This salinization type is characterized by reduced respiration intensity of plants, worse photosynthesis and activity of some ferments as well as by decelerated absorption and evaporation of water and by increased water content. At the same time the plants develop a halosucculent structure, i.e. leaves become more juicy, the number of cells is decreased but the cells become larger. The number of stomata is drastically increased and their size is larger. All this also leads to a higher transpiration intensity in plants of given salinization types (Strogonov and Ivanitskaya, 1954).

It is necessary to dwell in more detail on plant-water exchange in connexion with the problem of irrigation by underground waters. As we have already mentioned, the transpiration intensity of plants in conditions of chloride salinization is drastically decreased, while in plants growing in conditions of sulphate and carbonate salinization it is considerably increased. Owing to this, the consumption of water by plants for transpiration during the vegetation period will vary according to the chemical composition of the irrigation water.

Special attention should be paid to the problem of the variation in the degree of salt resistance of plants during their ontogenesis. As far back as 1884, Batalin noticed the low resistance of halophytes grown in a non-saline environment to a sudden salinization of the soil. Thus, even halophytes adapt themselves, in the process of ontogenesis, to an ever-increasing salinization during the vegetation period, on salted soils and salines.

According to investigations carried out by E. M. Kovalskaya in 1945, plants are especially sensitive to salinization at the very beginning of vegetation, during the period in which generative organs are formed and during the phase of budding and blossoming. Thus, in the course of their individual development the salt resistance of plants changes. A certain reduction of salt resistance during critical periods (with regard to salinization) makes it necessary to deal with greater care with irrigation by salt water during these periods in the development of plants.

Up to now the salt resistance of plants has not been sufficiently studied from the standpoint of the salt resistance of different crops as it is related to the quality

TABLE 1. Variation of water content and transpiration intensity of cotton leaves in conformity with soil salinization type[1]

Soil salinization type	Salt contents in soil	Water contents			Transpiration intensity				
		General (total)	Free	Bound	Per whole plant	Per 1 gm. of damp weight of a whole plant	Per 1 gm. of damp weight of leaves	Leaf surface per hour	Percentage per hour per water of a living plant
	%	%	%	%	gm./hr.	gm./hr.	gm./hr.	gm./1 m²	%
Control	—	78.2	59.97	40.03	33.60	0.51	1.18	258.5	61.60
Sulphate	0.8	79.3	55.48	44.52	26.40	0.52	1.11	240.0	63.24
Chloride	0.8	82.5	48.24	51.76	10.40	0.45	0.86	218.9	54.22

1. According to B. P. Strogonov and E. F. Ivanitskaya, 1955; K. A. Badanova, 1955.

TABLE 2. Variation of the anatomical structure of the cotton leaf in conformity with different salinization types[1]

Soil salinization type	Salt contents of soil	Leaf surface	Surface of one cell	Number of cells over the whole leaf area	Number of stomata in the field of vision	Size of stomata and cells		Leaf thickness	Parenchyma height	
						Transverse	Cross		Columnar	Spongy
	%	cm.²				mγ	mγ	μ	μ	μ
Control	—	50.2	1 812	27 704 000	13.5	28.7	20.9	210.6	90.0	90.8
Sulphate	0.8	25.1	849	27 208 000	15.0	25.4	20.5	280.6	136.0	137.6
Chloride	0.8	20.5	2 728	7 505 000	7.4	28.2	20.8	315.8	138.4	149.4

1. According to B. P. Strogonov, E. F. Ivanitskaya and M. K. Kerefova, 1954.

TABLE 3. Resistance of variety C–460 cotton plant epidermis cells to 1 m. solution of sodium chloride[1]

Condition	Leaf stray	Number of living cells	Duration of experiment in hours
Fresh	9th	15 ± 2.3	7
Saline	9th	29 ± 1.6	
Fresh	8th	4 ± 0.7	8
Saline	8th	12 ± 1.8	

1. According to P. A. Henckel, 1950.

of salinization. Most of the data available in literature on the salt resistance of plants either deal with chloride salinization alone or are given in a very summary form. This probably explains the fact that the same plant, in the works of different authors who studied it under different conditions, is described sometimes as "very salt-resistant", sometimes as "very unresistant" and sometimes as possessing "mean resistance". Such is the case, for example, of the sunflower, for which the data on salt resistance are very contradictory. The sunflower is probably distinguished by greater resistance to chlorides than to sulphates. The cotton plant, on the contrary, is more resistant to sulphate salinization. Beet is comparatively less resistant to both types of salinization, although sulphates are less harmful for it.

One of the first tasks confronting science in this field is to carry out experiments on the salt resistance of specific species of cultivated plants in varying conditions of soil salinity.

In the case of long utilization of saline drained subsoil waters for irrigation it is necessary to take measures to prevent soil impregnation with salts and to increase the salt resistance of plants.

In the light of what has been stated above it is very important to be able to diagnose the degree of salt resistance of plants. At the present stage of the development of science the principal methods of investigation are those of comparative estimation of salt resistance. Sometimes the most salt-resistant plant species is taken as a standard. But comparative methods give correct results only when systematically related forms are investigated, preferably the forms within the framework of a species, i.e. when we deal with various sorts.

One of the methods for estimating salt resistance is to study the germination of seeds in salt solutions. It is considered that the more salt-resistant the plant, the better it germinates in solutions containing high concentrations of salts. In 1934, Stratz compared germination of halophyte and glycophyte seeds in this way, and established that in principle no difference exists between halophytes and glycophytes as regards germination of seeds in salt solutions except that glycophytes stop germinating in less concentrated solutions. The seed germination method of determining salt resistance of crops was used by L. I. Seergeev (1936), V. S. Sharadakov (1948), V. A. Novikov (1936), V. A. Burygin (1942) and B. P. Strogonov (1949).

One of the disadvantages of this method is that it gives an idea of the salt resistance of plants at the early stage of their development only, while for a thorough knowledge it is necessary to have an idea of the salt resistance of plants during the whole period of ontogenesis, since this property is not constant and varies with the development phase.

B. P. Strogonov and L. A. Ostapenko (1941) offered a method of determining salt resistance of plants according to the intensity of chlorophyll disintegration in the leaves when placed in salt solutions. This method is based on the recognition of the fact that plants possessing increased salt resistance have a stable chlorophyll-protein system (Strogonov and Ivanitskaya, 1954). Plant leaves cut off under water are placed in a water sample taken from salt-impregnated soil, in salt subsoil water or in salt solutions with concentrations of salts of from 2 to 4 per cent. In order to prevent the leaves from fading the experiment was made in scattered light.

An indication of the degree of plant salt resistance is the rapidity of the appearance of salt spots caused by chlorophyll destruction under the influence of salts. In salt-resistant plants destruction of chlorophyll usually begins much later and develops less intensively than in non-salt-resistant plants. It should be mentioned that this method can be applied only to those plants that are grown in saline conditions. P. A. Henckel and S. S. Kolotova (1947) offered a comparative macroscopic method of determining the salt resistance of the cotton plant. It seems to be a variant of the method described above. The cut-off cotton leaves are placed in a 0.1 m. solution of potassium chloride or, better, potassium sulphate so that their petioles only are submerged in the solution. The flasks with the plants in them are exposed to direct sunlight. Within 30 to 60 minutes spots of salt burns appear on the leaves. The rapidity of the appearance of salt burns and their area on the leaf are used to measure the degree of salt resistance, which is expressed in terms of a five-point scale—a degree based on observation (i.e. no spots, very faint spots, faint spots, strong spots, very strong spots).

In addition, Henckel in 1950 elaborated a macroscopic method of determining salt resistance of plants which can be applied to different plants.

This method consists in the following: Plant sections (leaf epidermis) are submerged for several hours in a 1.0 m. solution of sodium chloride; the number of plasmolized cells in the microscope's field of vision is then computed and the average number of cells determined; five fields of vision should be taken, each section having only 30 fields of vision. A repeated verification has shown that this method can be applied to the estimation of the salt resistance of the cotton, tomato and alfalfa plants.

As is evident from Table 3, this method reveals clearly the differences in the degree of salt resistance of cotton plants grown in saline and in fresh conditions. Thus, of all the methods we have considered above the most satisfactory results are obtained by a comparative macroscopic method of analysing salt resistance.

This method can probably also be used to diagnose the salt resistance of those species which are cultivated on a saline substratum. The methods of diagnosing salt resistance may become of great importance for seed growing and selection. In our opinion selection of seeds of salt-resistant plants for this purpose should be carried out with a preliminary diagnosis for salt resistance of those plants which are distinguished by the largest productivity on a saline soil. Plants can possess the largest productivity on a saline soil in two cases: (a) when they are growing on a weakly salt-impregnated lot—this may quite easily occur, as wide variations of soil salinity exist; (b) when they are distinguished by simultaneous high productivity and salt resistance, the latter resulting from perfect adaptation to saline conditions.

As has been shown by corresponding investigations with the cotton plant carried out in Central Asia and Azerbaijan, large and productive cotton bushes on salt-impregnated soils are in most cases the most salt-resistant plants.

The picture of extreme heterogenity of cotton bushes on salt-impregnated soil is well known to all those who have lived or worked in areas in which salt-impregnated soils are abundant.

When breeding salt-resistant species, it is necessary to make wider use of intraspecific crossing of plants differently adapted to soil salinization. For this purpose B. P. Strogonov (1954) worked out a method of couple selection for intraspecific crossing. One of the plants in the couple is very salt-resistant (plant from a heavily salinized field) and the other is very productive (plant from a weakly salinized field). The posterity obtained as a result of this crossing proved to be far more salt-resistant and productive. Since intraspecific crossing was applied it is natural that no splitting of characteristics in the posterity was observed. The seeds obtained from intraspecific crossing must be sown the next year in a salt-impregnated soil. After that, a repeated selection of seeds from the most salt-resistant and productive plants should be made. These seeds can be used as initial material for the multiplication of productive plants adapted to salinized soil. Intraspecific crossing of cotton differing in its degree of adaptation and productivity according to the version and sort, increases the weight of the raw cotton in the boll from 9 to 37 per cent. Cotton grown from seeds resulting from intraspecific crossing in conditions of salinized soil shows an increase of the crop from 7 to 43 per cent. Moreover, the technological properties of the fibre are improved.

A considerable increase of salt resistance and productivity was obtained in cotton and wheat by the preparation of plants for salinization before sowing.

The fact that plants adapt themselves to a considerable extent to salinization in the course of their ontogenesis is already evidence of the possibility of working out such a method. The adaptation of plants can develop comparatively easily when they are young and pass the phase of seed turning up. The special plasticity of the organs when they are young was more than once pointed out by Darwin, I. V. Michurin and K. A. Timiriazev.

Taking as a basis the plasticity of a young plant and the enormous influence of the environment, we elaborated (Henckel and Kolotova, 1949; Henckel, 1954) a principle and methods for increasing considerably the salt resistance of plants.

One of these methods was based on the influence of hypertonic salt solutions on swollen seeds. After a long search for the most rational methods for increasing salt resistance and productivity of plants on a saline soil we decided to apply the following technique. Swollen cotton seeds are subjected to the influence of 3 per cent sodium chloride solution or van Hoff solution for a period of an hour. After that the seeds are rinsed for 1½ to 2 hours in water (preferably in running water), and then sown in the field. Rinsing is important for the rehabilitation of the turgor of the seeds and in order to prevent their germinating capacity from being affected. Already sapplings of experimental plants sharply reduce absorption of harmful salts: in particular chlorine from the surrounding solution (Table 4).

TABLE 4. Influence of pre-sowing salinization tempering of wheat on chlorine absorption by 10-day-old plants during 24 hours[1]

Experiment version	Chlorine absorption	
	mg.	Per cent of the control
Control (without treatment)	20.65	100
Treatment with van Hoff solution	8.75	44

1. According to Henckel, Kolotova and Scherbakov, 1944.

As has been shown by similar experiments, in plants subjected to salinization tempering the metabolic intensity (respiration), fermentative activity (peroxidase, dehydrase), absorption and consumption of water (transpiration) are reduced, and the colloidal and chemical properties of the protoplasm changed (elasticity of the protoplasm is decreased, while its viscosity is increased).

As a result of the deterioration of the elastic properties of the protoplasm, experimental plants reduce their drought resistance while, as the viscosity increases, they improve their heat resistance. The salt resistance, as determined by two methods (comparative microscopic and macroscopic), proved to be much higher in experimental plants. Numerous vegetation experiments showed a considerable increase, from 15 to 30 per cent, in the productivity of experimental cotton as compared with the control.

Later, however, it appeared that our method does not always give positive results. The analysis of this phenomenon showed unmistakably the positive influence of pre-sowing salinization tempering on chloride salted soils and less reliable results on sulphate salted soils. As we have already mentioned, reactions of plants to chloride and sulphate salting are different.

Proceeding from this last fact, Henckel (1957) worked out a special method of increasing salt resistance when sulphates dominate in the soil. As yet the method has been checked only for millet, with which a vegetation experiment has been conducted. The essence of the method is the following. Millet seeds were placed for 24 hours in a 0.2 per cent solution of magnesium sulphate and then sown in the field. The soil was salinized by sodium phosphate and had 0.15 per cent sulphur. The results of the investigation showed that experimental plants proved to be much more salt-resistant and gave a higher yield.

It follows from all that is stated above that the decisive conditions for the application of salt water to irrigation are its salt content, absolutely and proportionately the amount and method of application of the irrigation water, the physical and chemical properties of the soil and the possibility of its salinization as well as the climatic features of the region. In other words, these are the factors which, in turn, determine the degree of salt resistance of plants.

We shall now give data on the importance of salt concentration in irrigation water for crops of raw cotton (Table 5).

TABLE 5. Raw cotton crop as a function of salt concentration in irrigating water, cnt./hectare[1]

Concentration of salts in irrigating water	Pre-frost crop of raw cotton		Total raw cotton crop		Total raw cotton crop for two years
	1952	1953	1952	1953	
gm./l.					
0.2–0.5	27.93	29.36	36.18	30.25	66.43
2–2.6	24.02	24.90	34.88	25.11	59.99
4–5.2	23.93	20.44	31.37	20.85	52.22
6–7.8	22.74	18.38	28.63	19.01	47.64
8–10.4	23.95	18.95	28.71	19.34	48.05

1. According to V. E. Kabayev, 1954.

As is evident from Table 5 the raw cotton crop is directly dependent on the concentration of salts in the irrigation water. The higher the concentration of salts in the irrigation water, the lower the raw cotton crop. The degree of mineralization of irrigation water, as is stated by V. E. Kabayev (1954), exerts an essential influence on crop growth, development and formation. As the salt content of irrigation water is increased, the vertical growth of plants is weighed down, the number of bolls formed on the bush decrease and the ripening of raw cotton is retarded. At the same time the weight of raw cotton in one boll does not change essentially.

It is interesting to compare data on raw cotton crops irrigated by drainage water in regions with different natural environments (Table 6). The data given in this table are evidence of the fact that the effect of using drainage water arises from its chemical properties and the natural environment of the region. Thus, for example, in the Ferghana region, where conditions for using irrigation water with a large content of salts (5–7 gm./l.) are favourable, it is possible to obtain the same crop as with irrigation by fresh water; this is not the case in other regions.

When they grow on salinized soils in which underground waters with a salt content of 2–8 gm./l. of solid residue are not deep, cotton plants and other crops make a good use of these underground waters (Table 7).

On this basis V. Legostaev (1957) concludes that in those regions where fresh irrigation water is insufficient, subsoil waters should be kept at small depths, which makes it possible to obtain good crops with a minimum consumption of irrigation water.

According to the communication by I. E. Elsukov (1933), in the Golodnaya steppe cotton and alfalfa irrigated by drainage water containing 8–10 gm. of salts per gm./l. gave 29 cnt./ha. of raw cotton and 62 cnt./ha. of alfalfa hay during two hay harvests.

We must not, however, think that utilization of saline subsoil waters for irrigation is not dangerous from the point of view of the salinization of the soil. Many investigators point out the fact that a long and careless application of salt waters can result in considerable salinization (Table 8).

As has been shown by V. A. Kovda (1946), soils irrigated by saline water with a salt content of about 3–5 gm./l. can be strongly salinized in a period of 2–4 years.

Summing up what has been stated above, it should be considered that water with a salt content of not more than 1 gm./l. is still usable for irrigation purposes while water with a salt content of more than 3 gm./l. is not recommendable for irrigation. But these quantities are conditional. In agricultural practice in the USSR water with a salt content of 10 gm./l. is often used for irrigation without considerable damage to the harvest. Waters with a high salt content are used when there are possibilities of removing periodically the salts accumulated in the soil and when the favourable conditions described above exist.

TABLE 6. Raw cotton crop irrigated by drainage water[1]

Experimental station	Mineralization of drainage water	Crop (in cnt./hectare)					
		When irrigated by drainage water			When irrigated by irrigation ditch water (*aryk*)		
		Before frost	After frost	Total	Before frost	After frost	Total
	gm./l.						
Buhara	1.0–2.0	46.7	2.9	49.6	49.1	3.1	52.2
Fergana	5.0–7.0	35.7	11.5	47.2	35.5	11.8	47.3
Khorezm	4.0–5.0	39.6	4.4	44.0	47.4	4.2	51.6
Charjom	5.3	37.9	2.7	40.6	36.4	5.3	41.7

1. According to V. M. Legostaev, 1956.

TABLE 7. Underground water consumption by cotton and lucerne as a function of its depth[1]

Cultures	Depth of underground waters								
	1 m.			2 m.			3 m.		
	Total consumption of water by plants	Including underground water		Total consumption of water by plants	Including underground water		Total consumption of water by plants	Including underground water	
	m.^{3}/ha.	m.^{3}/ha.	%	m.^{3}/ha.	m.^{3}/ha.	%	m.^{3}/ha.	m.^{3}/ha.	%
Pakhta-Aralsk Experimental Station (Observations during 7 years)									
Cotton	11 700	9 140	78.0	5 820	1 830	34.0	4 780	267	5.6
Lucerne	20 350	15 800	77.9	21 870	15 050	68.9	11 380	1 730	15.3
Buhara Experimental Station (Observations during 6 years)									
Cotton	11 050	5 400	48.9	10 075	1 720	17.1	8 920	320	3.6
Lucerne	22 550	12 750	56.6	17 780	6 780	38.2	13 760	2 110	15.7

1. According to V. Legostaev, 1955.

TABLE 8. Salt content (as percentage) in air-dry soil (0–100 cm. soil layer) as a function of salt concentration in irrigating water[1]

Concentration of salts in irrigating water	Salt content before beginning of the experiment, in 1952		Amount of salts brought out by irrigating water during two years	Salt content in the soil in autumn of 1952		Salt content in the soil in spring 1953, after washing		Salt content in the soil in autumn of 1953, before washing	
	Solid residue	SO_4		Solid residue	SO_4	Solid residue	SO_4	Solid residue	SO_4
gm./l.									
0.2–0.5	0.242	0.018	5.39	0.138	0.020	0.128	0.014	0.104	0.015
2–2.6	0.192	0.025	30.01	0.252	0.062	0.196	0.045	0.168	0.077
4–5.2	0.145	0.018	58.72	0.235	0.078	0.198	0.064	0.273	0.134
6–7.8	0.186	0.017	87.64	0.290	0.110	0.278	0.102	0.434	0.202
8–10.4	0.166	0.022	116.25	0.324	0.144	0.318	0.113	0.548	0.253

[1] According to V. E. Kabayev, 1954.

Concluding our report, we should like to emphasize that only by applying the whole complex range of measures—including both land improvement and biological measures—can real conditions be created for increasing the salt resistance and productivity of plants on salinized soils. If artificial drainage and natural run-off are provided, it is possible to arrive at a successful utilization of saline underground waters of a certain salt concentration and quality and thereby to grow and harvest crops where at present this is hardly possible.

RÉSUMÉ

Physiologie des plantes consommant de l'eau saline

(P. A. Henckel et B. P. Strogonov)

La possibilité d'employer pour l'irrigation les eaux salines de drainage est étroitement limitée en raison de leur forte teneur en sels nocifs pour les végétaux; elle est fonction d'abord de la concentration et de la nature des sels qu'elles contiennent en solution, puis du degré de résistance des plantes considérées à l'égard de ces sels.

Dans les terrains naturellement salins, le degré de sensibilité et de résistance des végétaux varie selon la teneur du sol en sels (carbonates, chlorures, sulfates, etc.) dont chacun correspond à un type déterminé de salinité.

Lorsqu'il s'agit de salinité en chlorures, on constate chez les plantes une réduction du métabolisme et l'apparition d'une forte halosucculence. S'il s'agit de sulfates et de carbonates, le métabolisme des végétaux est sensiblement plus élevé et des tendances au xéromorphisme se manifestent nettement.

Les échanges hydriques de la plante et du milieu varient également selon le type de salinité. En présence de chlorures, l'intensité de la transpiration diminue rapidement mais elle s'accroît au contraire fortement en présence de sulfates et de carbonates. La consommation d'eau qu'entraîne la transpiration varie donc au cours de la période de végétation selon la nature de la salinité.

Lorsqu'on irrigue un sol à l'aide d'eau saline, il convient de doser très exactement la quantité et la concentration des sels en tenant compte du degré de résistance aux sels des végétaux considérés. On peut utiliser des eaux salines jusqu'à concurrence de 2 g par litre sans causer de dommages sensibles aux plantes. Au-delà de cette proportion de sels et à moins que l'irrigation ne soit réglée en conséquence, on provoque une réduction brutale des rendements et une salinisation secondaire du sol. Cependant, le degré critique de salure des eaux d'irrigation dépend du degré de toxicité des sels en solution, de la résistance des plantes à ces sels et des propriétés physico-chimiques du sol.

Si l'on doit se servir longtemps d'eaux de drainage salines pour l'irrigation, il faut prévoir des mesures contre la salinisation du sol et des moyens d'augmenter la résistance des plantes aux sels.

Pour accroître cette résistance aux sels des végétaux, il importe de pousser les opérations de sélection et de culture des semences de façon à obtenir des variétés résistantes, et, pour cela, de recourir aux méthodes tant microscopiques que macroscopiques de détermination de cette résistance. Pour obtenir des variétés résistantes, il convient d'appliquer largement le procédé du croisement en utilisant des plantes diversement adaptées aux sols salins.

Pour accroître la résistance des plantes dans un sol modérément chloruré, il est nécessaire, avant de semer, de traiter les semences à l'aide de solutions salines. En faisant gonfler les semences (de coton, de blé, de millet, de betterave sucrière) pendant une heure dans une solution de chlorure de sodium à 3 %, puis en les lavant pendant deux heures à l'eau, on obtient une augmentation de rendement de 15 à 30 %. Lorsqu'il s'agit de sulfates, les graines (de millet) doivent être traitées pendant 24 heures avec une solution à 0,2 % de sulfate de magnésium.

En recourant largement à toute la gamme des procédés de restauration du sol et des méthodes biologiques propres à augmenter la résistance des plantes aux sels, on pourra utiliser avec de bons résultats les eaux de drainage salines pour l'irrigation et accroître ainsi le rendement des plantes cultivées.

DISCUSSION

M. EL-GABALY. (1) Do you measure the effect of SO_4 and Cl on equal concentration or equal osmotic pressure?

(2) You mentioned that water with a salt concentration of 1 gm./l. could be used successfully for irrigation. Is that irrespective of the composition, the soil texture?

(3) What is the effect on salt tolerance of immersion of seed in salt solution?

P. A. HENCKEL. (1) Concentrations—equal; osmotic pressure—about equal.

(2) Where the concentration of salts is of the order of 1 gm./l., it is easily tolerable in every case. When it reaches 5 gm./l. and more, the influence could be decisive on both factors.

(3) It results in adaptation, the essence of this being the formation of labile protein-salty compounds.

A. K. KHUDAIRI. Do the seeds produced from the treated plants carry the same salt tolerance when planted again?

P. A. HENCKEL. Yes, at least during two subsequent generations, as was observed; there is, however, a definite progressive reduction of tolerance.

G. DOWNES. (1) What is the salinity of the soils in which the increased yields were obtained after treatment?

(2) Is this only an experimental procedure or has it been used in practice?

P. A. HENCKEL. (1) In natural conditions, from 0.075 to 0.12 per cent Cl.

(2) Quite practical, it has been tested in many areas of Azerbaijan and Central Asia.

G. REPP. (1) Under what conditions, such as total soil salinity, is Henckel's method effective?

(2) Was this method tested under field conditions?

P. A. HENCKEL. (1) The method of enhancing salt tolerance may be applied only on slightly or moderately salinized soils. The method described is of no value where amelioration is needed. Good results are to be expected with salinities of about 0.1–0.15 per cent Cl.

(2) The method has been investigated in the laboratory and on the field-scale for a long time. During the year 1956 the method was tried on an area of 1,000 ha. in Azerbaijan with a 20 per cent increase in the crop.

THE SALT TOLERANCE OF PLANTS: BASIC RESEARCH AND TESTS

by

GERTRAUD REPP

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Salt tolerance is an important property for all plants which, at any time during their life cycle, are exposed to the effects of salt. Such effects may be temporary, e.g. when roots pass through saline soil layers, or permanent, as in the case of halophytes.[1]

Salts in the above sense include water-soluble chlorides, sulphates and carbonates, mainly of sodium and magnesium but also of boron, which are taken from the soil in much larger amounts than could be absorbed in the normal metabolism of the plant.

In arid zones, as is well known, the salt content of the soil is a serious problem in agriculture. Basic research on the salt tolerance of plants is therefore important in relation to the use of salt lands, and should help in the choice of the most suitable plants for cultivation.

An excellent example of natural salt tolerance is afforded by the halophytes. Over a period of years I have tried to clarify the mechanism of salt tolerance by experimental ecological investigations in salt deserts, salt steppes and coastal areas.[2]

Once the different physiological and morphological salt adaptations are known in their special importance for the general salt tolerance, it should be possible to use them as tests for selection of salt-tolerant species and varieties in agriculture.

The investigations were made partly on halophytes and partly on cultivated plants in salt soils in northern and central Europe, in the United States of America and in the Sahara Desert. It may be pointed out, however, that the following results only concern the plants which are not able to excrete the absorbed salts, since the cultivated plants also belong to this group. The investigations are not yet completed but I should nevertheless like to report on my findings up to the present, and thus to provide a contribution to the explanation of this complex problem.

SURFACE SALT EFFECTS

Morphological adaptation

Surface salt effects may arise as a result of: (a) wind-transported salt spray; (b) flooding by salt water, especially in coastal areas; (c) salt efflorescence of the soil which may be dissolved by dew, rain or transpiration moisture and thus brought into biological activity.

Investigations in salt steppes and coastal areas [13][3] showed that halophytes have a very low wettability, so that salt solutions drop off the plants and hence cannot attack them (see Table 1). Often, moreover, these plants are covered with hairs (*Obione, Artemisia*) or the leaves have a thin coating of wax (*Lepidium, Statice, Puccinellia*).

TABLE 1. Wettability of halophytes

Plant	Static angle, in degrees, by Linskens' method[1]
Suaeda maritima	100
Spergularia salina	106
Puccinellia peisonis	107
Lepidium cartilagineum	114
Aster tripolium	119
Salicornia herbacea	120
Artemisia maritima	180
Obione portulacoides	180

1. According to Linskens' scale: > 90° = low wettability surface; 180° = unwettable surface.

In addition, in halophytes the resistance to penetration of salt solutions is increased by thickening of the

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[1] In addition to the salt content of the soil, the plants are sometimes also exposed to so-called surface salt effects on stem and leaves by salt efflorescences and wind-borne salt spray, e.g. in coastal areas.

[2] G. Repp, 1939, 1945, 1956, 1957, 1958.

[3] The figures in brackets refer to the bibliography on page 161.

external cellulose wall and of the cuticle. The cuticle is not nearly so thick as in xerophytes, but is on both sides of the leaf considerably thicker than in plants growing in equally moist but salt-free localities (see Table 2).

TABLE 2. Thickness of epidermal layers of coastal halophytes

Plant	Cuticle		External cellulose wall	
	Upper side	Under side	Upper side	Under side
	μ	μ	μ	μ
Statice limonium	3.8	3.2	9.6	8.0
Triglochin maritima	2.9		12.2	
Plantago maritima	2.8		11.2	
Aster tripoleum	2.7	2.5	6.8	6.4
Oblione portulacoides	2.5	2.5	6.4	6.4
Sueda maritima	2.0		6.4	
Salicornia herbacea	1.6		5.7	
Range of values for 20 different glycophile meadow plants	0.3–1.6	0.3–1.6	2.2–4.8	1.6–4.8

The absorption of salt water by the shoot is correspondingly low. In coastal halophytes it amounted to 4 per cent in 12 hours on the average, compared with 40 per cent when the cut stem was placed under water. Infiltration through the stomata is prevented by the air content of the leaves. Because of the above factors and form of adaptation, halophytes are not harmed by sea water or salt efflorescence of the soil.

CELL-PHYSIOLOGICAL ADAPTATION

Not only the above-mentioned anatomical forms of adaptation protect the halophytes from surface salt effects. All halophytes exhibit an extremely low permeability of the plasma to hypertonic salt solutions [14]. This low salt permeability was apparent not only with pure NaCl, but also with balanced solutions of NaCl and $CaCl_2$ and with sea salt. The state of plasmolysis remained unchanged for days, and the cells died before permitting penetration of the salt solution.

With surface salt effects, e.g. during evaporation of sea water or dissolution of salt efflorescences, dangerous salt concentrations may occur on the surface of the shoot. The presence of a permeability barrier, in addition to the water-repellent nature, produces a further efficacious protection against surface salt attacks.

With non-halophytic plants such barriers mostly do not exist. As is well known, dune plants and shelter-belt plants suffer serious damage from wind-borne salt; hence the salt must penetrate, and in fact Boyce [3] found in leaves of dune plants exposed to the wind a chloride content five times as high as in leaves not so exposed. Since the salt permeability of glycophytes is apparently not so low, the water-repellent habit can be the more decisive. Species with low wettability and/or a thick cuticle will therefore suffer less damage from surface salt effects. This is important in the selection of trees and shrubs for shelter-belts, especially in coastal areas.

ADAPTATION TO THE EFFECTS OF SALT FROM THE SOIL

Salt permeability of the plasma

In practice, it is very difficult to study methodically the salt permeability of the root cells of plants growing in the soil. It may, however, be assumed that the behaviour of the roots will be similar to that of the shoot; completely opposite behaviour in respect of salt permeability is at least highly improbable. In saline localities, the salt concentration in the soil solutions can in some cases become very high. The presence of a cell-physiological "permeability barrier" against such salt fluctuations in the soil is therefore of very great ecological importance.

Whether such low salt permeabilities occur in the presence of weakly concentrated (hypotonic) salt solutions also is yet to be determined. From the uncompleted tests made so far, it may be guessed that within a certain hypotonic range of concentrations saline solutions can still permeate. Even though there might be a certain selectivity in respect of the concentration and chemical nature of the salts taken up from the soil, the inevitable increase of the internal salt content of the plants shows that together with the nutritive salts the other soluble salts are also taken up from the soil. The former are utilized in the metabolism; probably Mg salts can also be at least partially utilized, since Mg is known to be an important plant nutrient. The excess sodium salts, however, must remain behind in the leaves during transpiration, and are stored in a dissolved, and hence biologically active, form in the cell-sap.

Only a certain group of halophytes, the types with salt secretion (*Statice, Tamarix,* etc.), can get rid of these excess salts by means of their own excretion glands. These types are therefore excepted in the following discussion.

Salt resistance of the protoplasm

The longer the period for which any part of a plant is traversed by saline transpiration water, the greater, naturally, is the quantity of salts remaining behind in the cell-sap. Many types of halophytes store the salts as chlorides, others as sulphates. The final result is, however, in all cases an increase of the internal salt concentration with increasing age. If the internal salt concentration becomes higher than the cell plasma can stand, then the older parts of the plant involved (e.g. the leaves) die off prematurely and are shed. With stem succulents such as *Salicornia* the older stem segments wither. Each premature death, however, means a loss to the plant of valuable material and assimilation surface. The higher the plasma salt resistance, the later and less frequent are such deaths, and the better adapted is the plant to a saline habitat.

The specific plasma salt resistance of the species is thus by far the most important factor for the salt tolerance of plants.

Even in halophytes, salt storage does not continue indefinitely. They are, however, characterized by a general level of plasma salt resistance considerably higher than in non-halophile plants [7, 9]. But even within the halophyte group there are different levels. The great ecological importance of the plasma salt resistance is shown by the fact that these differences have a quite decisive influence on the salt amplitude of the various halophyte species in their natural habitats [13].

The rate of internal salt increase is distinct from the specific cell-physiological absorption capacity—also very highly dependent on the actual salt content in the root region. Both of these may vary not only with time, but also with depth in the soil. The ecological investigations showed repeatedly that, for example, the leaves of plants whose roots reach down to layers of low soil salt content are considerably longer-lived. Germination and early development are thus critical stages in saline habitats, and the seedling is often lost before its roots manage to reach the less saline soil layers [9]. However, once the plants have got over this stage, and are established, they can often be seen growing unharmed in the midst of thick salt efflorescences.

For the growth of the roots, however, the work of the cells is also responsible; and it is clear that species with higher plasma salt resistance also have a better chance of making their way unharmed through very saline soil layers.

Succulence adaptation

Comparative tests on young and old parts of the same plant showed that increase of succulence can have a regulating counter-effect to the increase of internal salt over a long period [17]. The increased succulence occurs mainly in types storing chlorides.[1] The increased succulence is always brought about by a great expansion of, and addition of water to, already existing cells; it is found similarly in many dicotyledonous glycophytes, when these fall under a saline influence.[2]

The degree of succulence adaptation is, however, specific to the species, and varies within wide limits both among the halophytes and also in non-halophile plants. Many species have a very pronounced "morphological plasticity"; in others, the older leaves die without appreciable previous increase of succulence.

Thus the frequently observed salt succulence also has a certain secondary significance for the general salt tolerance of plants, and may counteract a low plasma salt resistance over a period, and thus delay dying off. In this connexion the inherited succulence of many halophytes (*Salicornia, Suaeda*) also has a beneficial effect. The specific facility of a species for succulence adaptation should therefore be particularly noted when selecting plants for cultivation in saline soils.

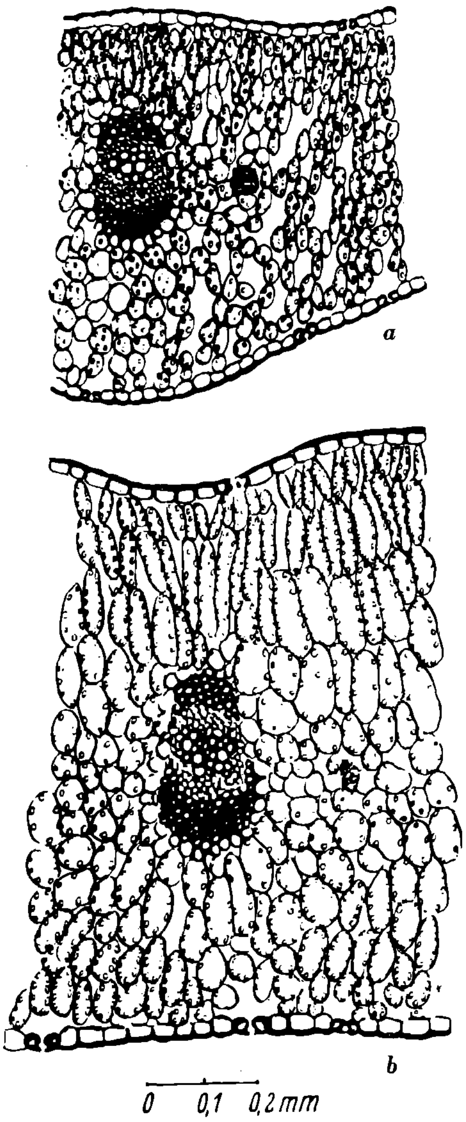

FIG. 1. Increase of succulence in older leaves: (a) young leaf, (b) old leaf.

The influence of the water economy on salt tolerance

Similar considerations apply to the specific water economy of the species. Among the cultivated plants, particularly, there are many species with unstable water economy. A badly balanced water economy is recognizable primarily by the high saturation deficits. In such plants stomatic regulation of transpiration sets in too

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[1] H. Walter, 1954.

[2] G. Repp, 1939, 1945.

TABLE 3. Maximum increase of succulence in saline soils, as percentage of initial succulence[1]

Plants	Increase of succulence	Relative salt tolerance (1 = highest)
	%	
Halophytes		
Lepidium crassifolium	360	1
Aster tripoleum	245	1
Lotus siliquosus	180	2
Taraxacum bessarabicum	160	2
Cultivated		
Lotus tenuis	136	2
Lotus corniculatus	86	3
Medicago sativa	55	4
Melilotus albus	17	4

1. G. Repp, 1939, 1956.

N. B. (1) For the initial succulence young leaves were used, with fully developed surface areas; the maximum succulence is taken from old leaves of the same individual plant.

(2) Succulence index $= \frac{\text{Water content in grammes}}{\text{Leaf surface (both sides) in dm.}^2}$.

late, excessive initial transpiration is followed by exhaustion, stomata closing and decreased transpiration, which of course leads to cessation of assimilation.

Water loss and wilting, however, at the same time give rise to a passive temporary increase of the salt concentration in the plant cells. In plants with a low plasma salt resistance, large diurnal variations of water content alone can cause the limiting concentration to be exceeded, and damage due to salt may occur. On the other hand, stable behaviour in relation to the water ecology can partly make up for a low plasma salt resistance.

In addition to the capacity for succulence adaptation, a stable well-balanced water economy is favourable for the salt tolerance. This applies particularly to plant species with a low plasma salt resistance, including cultivated plants.

RELATION BETWEEN PLASMA SALT RESISTANCE AND THE WATER AND SALT ECONOMY OF PLANTS

Plasma salt resistance and suction power

If the plasma salt resistance is sufficiently high, all the problems of water economy and drought resistance are automatically solved.[1] It is known that, in plants growing on saline soils, the osmotically active substances in the cells consist mainly of the salts taken up and stored [17, 18]. These also provide the (active) osmotic component of the suction pressure of the plants. The other component is the (passive) water loss due to transpiration. The suction pressure is, however, the sole factor which determines whether or not the plant can take up water from the soil.

Water economy and drought resistance on saline soils are therefore primarily dependent on the salt economy of the particular plant. The higher the plasma salt resistance, the larger the amount of salts that can be stored in the cells, and the higher the osmotic values and the active suction pressures developed by the plant. The higher the plasma salt resistance, the less also is the danger of salt damage on loss of water by the cells, and the more likely is the plant also to support a passive increase of the suction pressure.

The physiological relations between water economy and salt economy are the same for all plants on saline soils, and are as follows: the storage of salt is limited by the plasma salt resistance; if this resistance is low, then the suction pressure is insufficient, the absorption of water and nutrients from the soil is inhibited, the plants are in a state of "hunger", and the balance between water intake and water consumption is thrown out of adjustment; the water deficit therefore increases; assimilation and substance production cease; stomata close up and transpiration ceases; dwarfed growth and withering ensue.

The difference between halophytes and cultivated plants is merely in the level of the internal salt concentration at which this chain of events sets in. This level is, however, determined only by the plasma salt resistance.

Inhibition of osmotic adaptation

An interesting observation on cultivated plants may be mentioned here.[1] A comparison was made of various plant species of the same age, cultivated close together on salt-free and saline soils in a salt steppe region undergoing improvement. Some of these species developed relatively high osmotic values in drought conditions on normal soil. On saline soils, where the organic, osmotically-active, substances are replaced by the salts taken up, a marked inhibition of this osmotic adaptation was observed (see Table 4).

This resulted in serious diminution of growth, and the appearance of dwarf plants which are of course completely useless from the agricultural point of view. The dwarfed growth is not a salt injury in the true sense, but is a type of "hunger state" due to the shortage of water, the resultant restricted intake of nutrients and the inhibition of the assimilation. In cases of salt injury to plants, the following two factors should be distinguished, although in practice they often occur together: (a) Salt poisoning—direct salt injury to the plasma—depending on the amount of accumulated salts in relation to the specific plasma salt-resistance of the species. External appearance: yellowing and withering, but without reduction of size. (b) Indirect injury resulting from water shortage. This is a result of the inhibited adaptation of osmotic value and suction pressure. External appearance: typical dwarfed drought growth.

The existence of these two, separate forms of injury explains why regular watering, i.e. elimination of the water shortage factor, so significantly ameliorates the

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[1] G. Repp, 1945.

TABLE 4. Inhibition of osmotic adaptation in saline soils

Plant	Total salt content in the root region	Maximum basic osmotic value
	%	Atm.[1]
Alopecurus pratensis	0.19	22.1
	0.35	16.2
Beckmannia eruciformis	0.09	24.1
	0.61	19.4
Poa pratensis	0.09	26.2
	0.61	18.1

[1] Determined by plasmolysis in different concentrations of glucose. This "basic osmotic value" (*osmotischer Grundwert*) is, in contradistinction to the osmotic value of expressed sap, independent of the daily variations of water-content in the cells. This basic osmotic value is thus a relative measure of the osmotically active substances inside the cells.

existence of plants in relation to salt injuries. The best example of this is rice cultivation, which can be carried out even on very saline soils.

Drought tolerance and salt tolerance

The problem of the ecological relations between halophytes and xerophytes is also of interest here. The view is often advanced that these two groups are ecologically equivalent, i.e. that xerophytes are also halophytes and vice versa. I should like to oppose this view. In the first place, it is observed over and over again in desert regions that xerophytes do not predominate in typical saline locations, although as the density of vegetation is very low there is certainly no competition. Indeed, in the transitional regions these desert xerophytes can often be seen in the yellowed condition typical of salt injury. In agreement with the foregoing, Stadelmann [16] showed that the plasma salt resistance of xerophytes, though higher than that of the mesophile glycophytes, is not nearly so high as that of true halophytes.

Drought resistance is thus not identical with salt resistance. For example, if a plant is known to be drought-resistant, it does not at all follow that it is also salt-resistant. As already pointed out, the osmotic adaptation, i.e. the active increase of basic osmotic value and suction pressure by mobilization of osmotic substances, may be inhibited on saline soils. Further, when cultivation tests by the Riverside method were made on some fodder plants which in the case of Saharan specimens showed themselves to be relatively drought-resistant [15], only very low salt resistance was observed. Many more such examples could be given, and the fact that xerophily is not equivalent to halophily has been confirmed over and over again during journeys in arid zones.

Halophytes, i.e. plants with high internal salt resistance, can, however, also be resistant to drought, since the water uptake is determined only by the suction power. Because of salt accumulation, this can be very high in halophytes, thus enabling the plants to exist even in dry locations. But from my observations I could assume that these locations are not in fact permanently dry. The characteristic halophyte communities are always found in the relatively more humid parts of arid zones. Some of the halophyte species grow only in such locations; on the other hand, other species also occur in dry locations. On close examination it is usually found, however, that there may occasionally be an accumulation of moisture at these "dry locations". These halophytes are often found in depressions in the terrain or in places where flooding occurs occasionally or on single occasions. In any case, the accumulated soluble salts in the plants can only be drawn from the soil, and for this to happen a certain amount of moisture in the soil is necessary.

It is not possible to say to what extent the predominance of salts, which is always found in the osmotically active substances in saline locations, is a type of "displacement reaction". However, if the suction pressure is based not on sugar and organic acids, but mainly on such salts, which are not important in the metabolism, the result is that more of the organic substances like sugar and organic acids become available for growth. The internal salt content also reduces the respiration [4, 6]. In any case, the halophytes show a definite tendency to establish a certain internal "salt level" even where the salt content of the soil is low. This saving of organic substances may contribute to the greater ability of halophytes, as compared with glycophytes, to overcome competition in saline locations. Thus from this point of view also the internal salt resistance, without which such salt accumulation would not be possible, is the decisive factor.

THE CELL-PHYSIOLOGICAL SALT RESISTANCE AS A TEST OF THE SALT TOLERANCE OF CULTIVATED PLANTS

As explained above, the plasma salt resistance is the key to the problem of salt tolerance. Recognition of this fact affords the basis for a cell-physiological method for testing the salt tolerance of cultivated plants. If preselection could be effected by this means, much time could be saved in the field tests.

Method

The short-term cell-physiological tests were carried out in conjunction with field tests.

In the field tests, which served as a check, the method used was that developed at the Salinity Laboratory, Riverside, California. The plots were watered with 1.5 per cent salt water, the salts being a mixture of NaCl and CaCl in equal proportions. The criterion adopted as a measure of the salt tolerance was the magnitude of the decrease of the yield of the area. This includes the effects of both dying off of individual plants and decrease in the production of plant substance due to salt effects, for both of which the resistance and efficiency of the cell are decisive.

The cell-physiological tests were made by placing surface tissue cuts (always from the lowest part of the stem) in NaCl solutions of different molar concentrations. After 24 hours the tissue sections were transferred to a weak hypertonic solution of glucose, where they remained for 3–4 hours. The normal plasmolysis (i.e. plasmolysis with a perfectly smooth external contour) was taken as a positive life-reaction. Care must be taken in regard to this smooth external contour, as the inner layer of skin of the protoplasm, the so-called "tonoplast", is usually some degrees more resistant, and mistakes may thus occur in the tests. All the tests were carried out in the same climatic conditions in Utah, in the summer of 1956.

Cell-physiological testing of various species and varieties. As shown in Table 5, the plasma salt resistance of the wild halophile plants under comparison, viz. *Salsola kali* and *Halogeton glomeratus,* is appreciably higher than that of the cultivated plants. There are also, however, significant differences between the values of plasma salt resistance among the cultivated plants themselves. These differences were quite consistent with the relative salt tolerance values observed in the field tests. It should be borne in mind that the "water shortage" factor was eliminated in the field tests by regular watering with salt water. The plants therefore exhibited direct salt injuries (yellowing and withering), but not the marked reduction of size which is typical of the combination of salt injury and water shortage.

Thus the cell-physiological pre-testing proved to be useful in the selection of plant species for saline soils. In order to show up differences between varieties of cultivated plants, however, the method needs further refinement. This can be done without difficulty by introducing intermediate concentrations in the test series. Further investigations are to be made. Resistance to other salts, such as sulphates and carbonates, can also be tested by this method.

Seasonal variations of plasma resistance. As the experiments showed, plasma salt resistance may vary seasonally within a certain range of values. Field tests[1] also showed seasonal variations in the relative salt tolerance. These seasonal variations may have a climatic cause. For example, field tests at Riverside indicated that the salt tolerance may be lower at higher temperatures. The observed variations of the plasma salt resistance were, however, low, and were not in the same sense for all the species.

The following conclusions can be drawn with regard to our investigations:

1. Cell-physiological testing can only give relative information, i.e. only for similar climatic conditions of the habitat. Since it is usual to take an assortment of the particular species and varieties of the plant specimens to be tested, and the method requires very little test material, this is not a serious disadvantage.
2. It is strongly recommended that different species should be investigated at times close together. Errors may, for example, be introduced if a species tested in spring is compared with another tested in autumn. Possibly one or two standard varieties should be used as comparison varieties. Since the cell-physiological test can be performed comparatively rapidly, there is no practical difficulty about the time factor.

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[1] C. R. Funk, 1954.

TABLE 5. Salt resistance of the protoplasm of various species of wild and cultivated plants

													Result of the field tests	
Mol NaCl	0.2	0.3	0.4	0.5	0.6	0.7	0.8	1.0	1.2	1.4	1.6	1.8	Salt tolerance (relatively)	Drought tolerance (relatively)
Wild plants														
Halogeton glomeratus	L	L	L	L	L	L	L	L	L	—L	+L	+		
Salsola kali	L	L	L	L	L	L	L	L	—L	—L	+	+		
Cultivated plants														
Sugar beet	L	L	L	L	—L	+L	+	+	+	+			high	low
Lotus tenuis (Los Baños, Spain)	L	L	L	+L	+	+	+	+	+				high	medium
Ervum ervillia (Africa)	L	L	+L	+	+	+	+	+	+				low	high
Vicia cracca (Russia)	L	L	+L	+	+	+	+						low	high
Medicago sativa (Provence, France)	L	—L	+L	+	+	+	+						low	medium
Medicago sativa (Utah, U.S.A.)	L	+L	+	+	+	+	+						low	medium
Lentil (Syria)	—L	+L	+	+	+	+	+						low	medium-high
Vicia faba (Africa)	+L	+	+	+	+	+	+						low	low-medium

L = plasma living, plasmolysis completely normal.
— L = plasma living, but some structural modification has already occurred, plasmolysis contour still smooth.
+ L = over 50 per cent of cells dead.
+ = nearly all cells dead.

Individual age and salt resistance of the protoplasma. One- and two-year-old plants of the same species showed no difference in the plasmatic salt resistance when the tests were carried out with plants growing in the same environment and in the same season.

Field experiments at Riverside, California, however showed differences in salt tolerance between seedlings and older plants. At Riverside, testing of salt tolerance is made by comparing the percentage decrease in the yield. This is of much value from the agricultural point of view, but ecologically it is only the end-result of quite a complex process of salt adaptation. The yield can be influenced also by secondary adaptations such as succulence and water balance, the latter also depending on the morphological and physiological qualities of the species. For the purpose of quick selection in plant breeding as well as for experiments in "salt-hardening", it is of practical importance to determine these different factors of salt tolerance.

Besides this, the seedlings which are still using the reserves from the seed and which do not have fully developed assimilation may react in a different manner. Therefore, for conducting cell-physiological salt-resistance tests it would be preferable to use young plants after the seedling stage, with normal assimilation, i.e. the cotyledons should be replaced by at least 3–4 normal leaves. Testing with such plants is easier as the tissues are still soft and a large number can be compared in a short time. Besides the above, this stage is very important for the final establishment of the plant in saline soils.

RÉSUMÉ

La tolérance des plantes à la salinité: Recherches et essais (G. Repp)

L'auteur s'est efforcé d'expliquer les principes fondamentaux de la tolérance des plantes à l'égard de la salinité au moyen de recherches écologiques expérimentales menées dans des déserts salins, des steppes salines et des régions côtières. Ces recherches ont porté aussi bien sur des plantes cultivées que sur des halophytes, qui constituent l'exemple le plus caractéristique de plantes ayant une tolérance élevée à la salinité. Ces recherches ont permis d'aboutir aux conclusions suivantes:

Contre les effets salins de surface (embruns marins emportés par le vent, submersion, efflorescences salines, etc.), les halophytes sont bien protégées. Ces plantes absorbent très peu l'humidité, tandis que leur cuticule et leur enveloppe cellulosique sont deux à trois fois plus épaisses que chez les glycophytes comparables. La perméabilité de leur protoplasme aux solutions salines hypertoniques est extrêmement faible.

Toutefois, les plantes prennent forcément au sol, avec l'eau qui leur est nécessaire, les sels dissous dans cette eau. Dans la mesure où ces sels sont inutiles au métabolisme ou ne peuvent être excrétés, ils restent en solution à l'intérieur des cellules. Si la concentration interne de sels augmente au point de dépasser celle que peut supporter le protoplasme, la partie atteinte de la plante meurt prématurément. Cette réaction intervient chez tous les végétaux qui poussent sur des sols salins. Le taux de concentration interne de sels auquel se produit ce phénomène dépend de la résistance spécifique aux sels du protoplasme de l'espèce considérée.

La résistance spécifique du protoplasme aux sels est donc le facteur primordial, et le plus important, de la tolérance des plantes à l'égard de la salinité. Chez les halophytes, cette résistance est en général bien plus élevée que chez les glycophytes; elle est toutefois sujette à des variations et celles-ci déterminent la répartition des diverses halophytes entre des habitats présentant des degrés différents de salinité.

Les besoins en eau des plantes poussant sur sol salin dépendent eux aussi de la résistance spécifique du protoplasme aux sels. Chez toutes les plantes, les sels accumulés ont tendance à prendre la place des substances organiques qui jouent un rôle dans le phénomène de l'osmose. Ainsi, c'est d'eux également que dépend cette force d'aspiration qui, seule, détermine la quantité d'eau que la plante retire du sol. Les plantes dont le protoplasme présente une résistance élevée aux sels sont donc capables d'une pression osmotique plus forte; elles sont aussi mieux en mesure de supporter une augmentation massive de cette pression due à la perte d'eau par transpiration, qui équivaut à une augmentation de la concentration interne de sels.

Pour les raisons susmentionnées, il arrive souvent que les plantes dont le protoplasme a une faible résistance aux sels (par exemple les plantes cultivées) ne peuvent pas, en temps de sécheresse, s'adapter grâce au jeu du mécanisme de l'osmose. Elles s'étiolent alors, car l'absorption de substances nutritives et l'assimilation du CO_2 sont également entravées par le manque d'eau.

La salinité a donc deux conséquences dommageables: d'une part, l'empoisonnement par les sels, qui provoque la décoloration et le flétrissement prématuré des plantes; d'autre part, le manque d'eau, qui entraîne le rabougrissement. Les deux conséquences apparaissent souvent à la fois.

Plus la résistance protoplasmique aux sels est faible, plus le bilan hydrique spécifique de l'espèce présente d'importance du point de vue de la tolérance de celle-ci à l'égard de la salinité. Lorsque le déficit de saturation résultant d'une transpiration excessive et d'une régulation imparfaite des stomates est élevé, il provoque une augmentation temporaire de la concentration de sels dans les cellules. En revanche, un régime hydrique stable provoque rarement le flétrissement et peut améliorer la tolérance générale à la salinité, particulièrement chez les espèces dont le protoplasme n'a pas une très haute résistance aux sels.

La succulence saline fréquemment observée est une adaptation morphologique de ces plantes à l'augmentation inévitable de la concentration interne de sels. Elle prend la forme d'une expansion des cellules qui se gorgent d'eau, principalement dans les feuilles, où les sels s'accumulent du fait de la transpiration. Ainsi se trouve retardée l'augmentation de la concentration de sels. L'adaptation par la succulence est ainsi, particulièrement chez les plantes ayant une faible résistance protoplasmique aux sels, un autre facteur favorable à la tolérance à la salinité.

Bien que, chez les plantes autres que les halophytes, la résistance du protoplasme aux sels soit en général inférieure à celle des halophytes, elle n'en est pas moins sujette à variations. Cette résistance protoplasmique aux sels étant un facteur essentiel de la tolérance générale des végétaux à la salinité, on a tenté de mettre au point une méthode cytophysiologique de mesure de la tolérance à la salinité.

Les résultats obtenus jusqu'ici avec diverses espèces de plantes cultivées concordent de façon satisfaisante avec ceux des expériences de contrôle effectuées en pleine nature. La résistance protoplasmique aux sels ne dépend pas de l'âge de la plante; on a pourtant constaté de légères variations saisonnières de cette résistance, liées probablement à la température. Il importe donc que toutes les mesures cytophysiologiques de la tolérance de différentes espèces à l'égard de la salinité soient effectuées à la même saison.

DISCUSSION

A. K. Khudairi. What was the highest osmotic value due to presence of salts found by Dr. Repp near the root zone of the halophytes, and how would it compare with that of cultivated plants?

I should like to make one comment concerning the osmotic values tolerated by date-palm; we have found that during germination and early stages of growth the date-palm can tolerate up to 14 atm. of sodium chloride solution.

G. Repp. I did not measure the osmotic pressure of the soil solution but the so-called "actual suction force" of the soil, which depends on water content, salt content and structure of the soil. For this method, solutions of sugar in different concentrations are used. The following suction forces have been found in a salt steppe in the root zone of *Suaeda maritima:* soil dry (5–6 per cent water content), salt content low, 18 atm.; soil dry (5–6 per cent water content), salt content high, 70 atm. (plants dying).

In a Saharan oasis the following suction force of the soil was found in fields of cultivated plants where the soil was slightly saline as a result of evaporation of irrigation water: water content 12 per cent, dry matter 4 atm.; water content 5.3 per cent, dry matter 13 atm.; water content 3.0 per cent, dry matter, 35 atm. (plants dying).

In a deserted, formerly irrigated, field the suction force was 120 atm. in the case of a water content of 9 per cent; this was due to high salinity caused by evaporation of slightly saline irrigation water.

J. N. Jewitt. Has Dr. Repp, during her work on desert plants, obtained information about the total salt content of these plants? The purpose of the inquiry is to form an idea of the amounts of salt removed when desert plants are harvested for fuel.

G. Repp. First, I think we must clearly differentiate between those desert plants which are xerophytes only, and those desert plants which grow on wet or dry saline soils in deserts and are able to accumulate salts due to their high plasmatic salt tolerance.

The internal salt content of such plants can be quite high. In halophytes growing on wet salt soils, ash contents of between 35–50 per cent of the dry matter have been found, of which 20–50 per cent was sodium; in the case of halophytes in drier salt soils the ash content was lower, 12–25 per cent only, depending upon various factors.

The salt accumulates mainly in the transpiring leaves, and not in the woody part used for fuel. It is doubtful if removal of such plants would significantly *decrease* the salt content of the soil.

On the other hand, if salt-accumulating plants die or drop leaves, they may actually *increase* the salt content of the soil surface; similarly, salt excreting plants would enrich the surface of the soil with salts. Both these phenomena are often observed in cases where the water table is low and where no upward salt movement through capillarity takes place.

C. A. Bower. With reference to making salt-tolerance tests on seedlings, it is important to realize that salt tolerance in various species depends upon the stage in the growth cycle. For example, beets are very sensitive to salinity in the seedling stage but very tolerant in later stages of growth. On the other hand corn is more salt-tolerant in the seedling stage than in later growth stage.

G. Repp. There is no doubt that the stage in the growth circle is important. Especially between seedling stage and adult stages there may be differences.

I think it would be desirable in certain cases, depending on the field conditions (e.g. the type of saline soil), to test the plasmatic salt tolerance both in the seedling stage and in a later stage of growth. In soils in which the salt accumulates on the surface, the germination stage is the most critical period for the plant. In soils in which the salts lie in deeper layers, this critical period occurs later, when the roots contact the saline layer.

D. A. **Denton**. Have you measured the osmotic pressure of the cell water of cultivated plants and halophytes? Or the osmotic pressure of the leaf cells of the date-palm, which is allegedly very resistant to salt?

G. **Repp**. The osmotic pressure in the date-palm was not studied by me. However, in my investigations on halophytes and cultivated plants I have always measured the osmotic pressures. For these measurements, I used the plasmolytic method which determines the so-called "basic osmotic value". It is independent of the daily change in the turgor and concerns primarily the osmotically active substances in the cell sap. In addition to the above method, the cryoscopic method was very often used for comparison.

I examined the seasonal change in the osmotic pressure as well as its correlation with the soil salinity. Besides this the ability of different species to increase the osmotic pressure under extreme conditions was also studied.

Abdul Hafiz. Is there any correlation between sugar concentration of cell sap and salt tolerance of plants?

G. **Repp**. Plants that are able to develop high osmotic pressure based on organic osmotic substances like sugar would certainly be better able to overcome the water difficulties which often occur in saline soils, i.e. the so-called osmotic (physiological) drought.

As a matter of fact, however, in saline soils the sugar is usually replaced by salts as osmotically active substances. These salts are taken up with the soil water and remain in the plant after transpiration. This happens in halophytes as well as in glycophytes (e.g. cultivated plants, when growing in saline soils).

Therefore, the actual sugar concentration in the cell sap is far less important than the salt concentration. For example, I found that some cultivated plants in normal soil are able to develop high osmotic pressure owing to the presence of sugar and the other organic substances. The same species growing in saline soil, where the osmotically-active substance in the cell mainly consists of the uptaken salts, showed much smaller maxima of osmotic pressure.

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SOME EFFECTS ON PLANTS OF SALT AND SODIUM FROM SALINE AND SODIC SOILS

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The effects of salt and sodium in the water and soils on plants and animals has long been the concern of those of us living in arid lands where salinity problems are numerous. The expansion of supplemental irrigation, the use of concentrated fertilizer, and even the use of soft water has increased the prevalence of such problems.

If we are to solve the perplexities imposed by salinity, we must know how the different ions affect soils, plants, and animals. At present we have far from a complete understanding. In the discussion to follow I should like to review some of the information available on how salts and exchangeable sodium affect plants. Bernstein and Hayward [2][1] recently completed an excellent review of the literature dealing with the physiology of salt tolerance. No attempt will be made here to cover the details of this information.

As a basis for understanding let us begin with some generalizations that seem well-founded. We are fairly certain that transpiration and water absorption do not directly regulate the rate of salt intake or its accumulation within a plant. The salt concentration of the cell sap of higher plants usually increases as the salt concentration in the soil solution increases, but it is not in direct proportion to the change. The concentration increase is generally greater in the parts above ground than in the roots, as illustrated in Table 1 which gives the osmotic pressure in the leaves and roots of some of our common cultivated plants. Salt damage may well take place in the roots before it does in the tops. Most plants have some selective adsorption of salts as evidenced by the fact that the composition of the cell sap is not the same as that of the soil solution. Salts are absorbed by the roots as ions from solution and not directly from the soil solids. After salts have been absorbed by the roots and entered the xylem, the movement upward is largely dependent on the rate of transpiration.

Tolerance to salt is genetically controlled but, like yield, its inheritance is much more complex than the simple Mendelian ratios which describe inheritance of such characteristics as disease resistance and flower colour. Salt tolerance in plants is in other ways like yielding ability in that it varies with climatic and environmental conditions.

TABLE 1. Osmotic pressures of expressed sap of leaves and roots of plants grown on sand cultures with graded additions of NaCl to the base nutrient solution[1]

Plant	Part	Osmotic pressure of expressed sap in atm.				
		Added NaCl, atm.				
		0	1.25	2.50	3.75	5.00
Onions	Leaves	10.4	8.6	11.3	—	—
	Roots	3.6	4.1	4.7	—	—
Peas	Leaves	10.5	14.2	16.8	—	—
	Roots	5.1	10.4	9.3	4.7	—
Beans	Leaves	8.3	9.1	9.3	11.3	11.4
	Roots	3.9	4.0	3.6	3.0	3.2
Cabbage	Leaves	9.9	11.9	12.7	11.3	11.9
	Roots	3.3	3.9	5.1	4.2	4.6
Tomato	Leaves	10.3	10.4	10.3	9.5	9.5
	Roots	2.9	6.9	—	4.1	5.0
Beets	Leaves	10.3	13.4	15.2	16.4	18.3
	Roots	2.6	3.2	3.4	3.7	4.0

1. From Bernstein and Hayward [2].

HOW SALTS AFFECT PLANT GROWTH

Salts in the soil solutions may adversely affect plants in several ways: (a) by osmotic inhibition of water intake into the roots; (b) by specific ion effects. The specific effect may be by toxicity or by influence on the nutrition. The nutritional upset may be as a result of insolubility or competitive adsorption of ions. Any one of these effects may be associated with enzyme activity within the plant and/or with morphological changes.

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[1] The figures in brackets refer to the bibliography on page 166.

Osmotic effects

We have all observed many instances in which, as the salt concentration was increased in the root zone, the growth decreased. Wadleigh and Ayers [8] have shown that growth decreased with increasing moisture stress, whether this stress was caused by a salt increase or a lack of available soil moisture. One rather disturbing fact is that plants under stress as a result of salt seldom show characteristic wilting. Some plants, however, suffer less retardation from salt then do others. These we tend to consider salt tolerant. Why these are tolerant we are not sure. We do know that water moves into, through, and out of plants as a chain reaction. It seems that as plant cells accumulate salt from the soil, the osmotic pressure of the cells increases, as does the power to extract water from the soil. With this salt concentration in the cells there is also a resistance to the loss of water by transpiration. This resistance may be of small significance because the diffusion pressure differences governing the loss of water from the leaves are many times greater than those regulating the entrance and movement. It is, then, evident that plants tolerant to salt can otherwise adjust to the adverse conditions so as to reduce the loss of water from the leaves. This adjustment appears to be accomplished by morphological changes such as thick cuticle, sunken stomates, reduced surface area, or succulence, that result in reduced evaporation into the atmosphere. These morphological changes are most apparent in halophytes and are generally accomplished at the expense of plant growth. Many of these morphological changes increase the rigidity of the plant, so that wilting symptoms are not apparent. Many salt-tolerant plants live under conditions where water is not limiting, at least during the time of vegetative growth. This includes all salt marsh plants and tideland plants. Some of these have high transpiration rates. Other tolerant plants have ample water during vegetative growth and may also have a high transpiration rate, but during periods of high moisture tension the plants are dormant or producing seed and the water requirement is low, as is the transpiration.

Repp [7] states that a major factor in salt tolerance is the resistance of the protoplasm. We know different species show different amounts of ion accumulation, and that there is an increase in the salt content of leaves with an increase in age. When the concentration becomes greater than the protoplasm can tolerate the cells die. Some plants increase in succulence with age when grown on saline soils. This succulence delays attainment of critical internal salt concentrations. It would be expected that the older the plant the more resistance it would have, as long as the critical concentration has not been reached. It seems that one reason for differences in salt tolerance between species may be the differences in the magnitude of critical concentration, and also the rapidity at which such concentration is reached. This may well be associated with the nature of the protoplasm, the ability of the plant to exclude salts, the degree of structural alteration that reduces transpiration, and the resulting desiccation and salt concentration. Plants that are considered drought tolerant have certain characteristics which enable them to extract water from the soil and also to prevent its loss from the plant. It is, however, evident that salt tolerance and drought tolerance are not the same.

Salt has been found to delay germination of seeds. This might be expected because of the reduced availability of water. The same, however, is true of increasing amounts of exchangeable sodium or increasing *p*H of the germinating medium. When the osmotic pressure remains constant, these different adverse conditions probably retard germination in different ways. Other conditions which influence germination include the age of the seeds, the moisture content, and the nutritional status of the plants from which the seeds were grown. As mentioned earlier, salt tolerance may change with age; hence there may be little correlation between salt tolerance of established plants and salt tolerance at germination.

Some other adverse effects of salt

Many plants are specifically affected by certain ions that accumulate in the plant, such as chloride in avocado [1] and other fruit trees grown on soils relatively low in salt.

We found barley more sensitive to $CaCl_2$ than to NaCl of the same osmotic concentration. For many plants the reverse is true. In this case the chloride content was the same in the tops as for the NaCl and less in the roots (from the calcium chloride), so that chloride accumulation could not be the cause.

When excess salt is present there are a large number of ions in solution. This reduces the chance for a plant root to absorb a specific ion needed for metabolism and thus the salt prevents the normal intake of needed ions.

SODIUM FROM SODIC SOILS

Not a great deal of concrete information is available on the influence of exchangeable sodium on plant behaviour, nor on the basis of tolerance to alkaline conditions. There is no assurance that salt-tolerant plants also have tolerance to excessive amounts of exchangeable sodium. Tolerance may vary with associated conditions. Some of the conditions are: (a) high sodium plus neutral salts; (b) high sodium and high *p*H; (c) high sodium and high carbonate and bicarbonate content.

The adverse effects on plants under these various conditions may result from: (a) high concentrations of sodium; (b) low calcium, magnesium and potassium availability, caustic hydroxyl content; (c) dispersion of soil with resulting poor aeration.

Hayward and Wadleigh [4] have suggested that the more tolerant species normally take in considerable amounts of sodium, while sensitive plants tend to exclude sodium and do so at the expense of calcium, magnesium and potassium intake.

The presence of neutral salts is beneficial in many instances. In saline-sodic soils they depress the hydroxyl concentration, and also restrict the soil dispersion, thus minimizing two of the three harmful effects found in sodic soils. In all cases, however, there is low availability of calcium, magnesium and potassium for the plants. Strangely enough calcium deficiency symptoms seldom if ever appear, even though the calcium content of the plant is greatly reduced. Chang and Dregne [3] have suggested that unique symptoms appear—these they propose to call sodium-induced calcium deficiencies. For alfalfa they take the form of reddish coloration of the lower leaves followed by a collapse of the petioles.

In using sodic soils or in making recommendations for their use, it is desirable to know at what limits of exchangeable sodium a preferred plant can be expected to grow. In our laboratory we have tried to establish tolerance limits. This seemed possible under controlled environmental conditions, but when we took field samples we found no correlation between growth of tall wheatgrass (*Agropyron elongatum*) and the exchangeable sodium in the soil, as indicated in Table 2. The soil samples were taken from among the roots of the growing plants in the field. Plants were selected from sodic soils and were rated according to their relative growth. The presence of salts in these soils has probably reduced the adverse effects of the high exchangeable sodium by preventing dispersion and depressing alkalinity. The grass was able to grow well at a percentage as high as 66 and to grow even at as high a percentage as 71.

TABLE 2. The range of values recorded for exchangeable-sodium-percentage (ESP), *p*H, and electrical conductivity of the saturated extract (EC_S); from analysis made on soil samples from the root zone of tall wheatgrass plants in yield rated areas.

Growth rating[1]	Range of measured factors		
	ESP	*p*H	EC_S[2]
1	7–66	8.2–9.3	1.3–3.9
2	2–69	8.2–9.3	1.2–3.8
3	12–55	8.3–9.3	1.2–4.5
4	13–71	8.3–9.6	0.9–4.8
5	9–74	8.3–9.7	1.0–4.8

1. The growth rating 1 was good, decreasing to 5 where there was no growth.
2. EC_S recorded in millimhos./cm.

SALTS AND ENZYME ACTIVITY

It was mentioned earlier that salts in the soil may regulate the enzyme activity within the plants growing in saline soils. This field is as yet unexplored but offers hope of a more complete understanding of the influence of salt on plant growth.

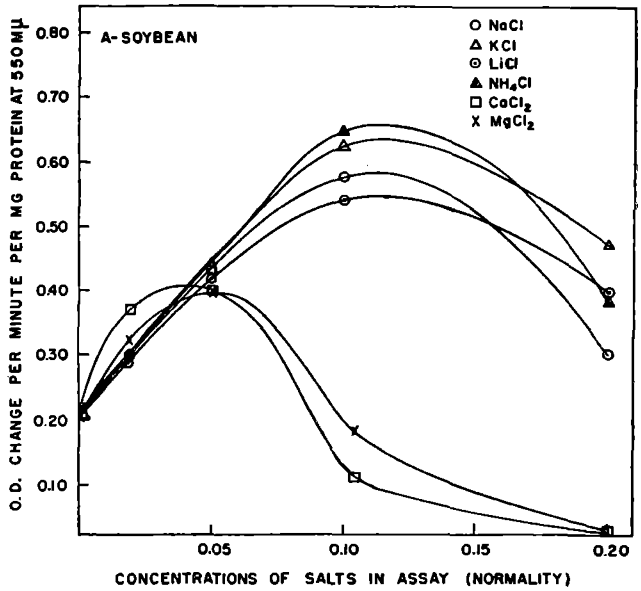

FIG. 1. Concentration of salts in assay (normality). (From Miller and Evans [6].)

Lundegårdh [5] has presented a theory of anion respiration in which he indicates a belief that the activity of the cytochrome system is controlled by the concentration of movable salt anions. He has shown that in living wheat roots the oxidation reduction balance of the cytochromes is raised toward a higher state of oxidation by a change of medium from water to salt solutions.

Miller and Evans [6] made a study of the influence of various concentrations and kinds of salt on the activity of cytochrome oxidase from certain higher plants. They showed that monobasic cations were more stimulating at low concentrations than dibasic, and less depressing at higher concentrations (fig. 1). When anions were varied they found that chloride, nitrate, sulphate, bromide, and iodide were about equal in their influence. The $H_2PO_4^- + HPO_4^=$ were best. $NaHCO_3$ was most inhibitory. The influence of salt was not osmotic. Such data on enzyme activity are not conclusive but they suggest ways in which salts may adversely influence plant growth. They also suggest reasons for beneficial response by some plants to low concentrations of salts. They certainly offer no explanation for the beneficial effects of *high salt concentrations* on the growth of such halophytes as *Salicornia*. Nor do they indicate how the enzyme systems of some plants are protected from the influence of high concentrations of salt.

RÉSUMÉ

Quelques effets sur les plantes des sels et du sodium des sols salins et sodiques (H. B. Peterson)

L'étude des effets qu'exercent les sols salés sur les plantes autorise à penser que le taux de pénétration ou d'accumulation des sels n'est pas directement commandé par la transpiration et l'absorption d'eau. Dans le cas des végétaux supérieurs, la concentration du suc cellulaire augmente habituellement avec la concentration des sels dans la solution du sol, mais non de façon directement proportionnelle. Pour une plante donnée, la concentration des sels est généralement plus forte dans les sommités que dans les racines. L'absorption des sels par les plantes est sélective, et la composition des sels n'est pas la même dans le suc cellulaire que dans la solution du sol. Les sels qui pénètrent dans les racines sont absorbés sous la forme d'ions de la solution du sol plutôt que de particules solides du sol. Lorsque des sels ont été absorbés et ont pénétré dans le xylème, leur mouvement ascendant dépend en grande partie de la transpiration. La tolérance d'une plante donnée à l'égard des sels est liée à la fois au milieu et à l'hérédité.

Les sels contenus dans la solution du sol peuvent exercer de différentes façons des effets nuisibles sur les plantes: *a*) inhibition osmotique de l'absorption d'eau par les racines; *b*) effets spécifiques dus aux ions. Ces effets spécifiques peuvent provenir de la toxicité des sels ou de leur influence sur la nutrition. Celle-ci peut être perturbée en cas d'insolubilité ou d'absorption concurrente d'ions. Chacun de ces effets peut être associé à l'activité d'enzymes au sein de la plante et (ou) à des changements morphologiques.

Rien ne permet d'affirmer que les végétaux qui tolèrent les sels tolèrent également des fortes quantités de sodium échangeable. La tolérance peut varier en fonction de diverses conditions associées: *a*) haute teneur en sodium, plus sels neutres; *b*) haute teneur en sodium et *p*H élevé; *c*) haute teneur en sodium ainsi qu'en carbonate et bicarbonate. Les effets nuisibles qui s'exercent sur les plantes peuvent être dus aux causes suivantes: *a*) excès de sodium; *b*) manque de calcium, de magnésium et de potassium; *c*) teneur en hydroxyle caustique; ou *d*) dispersion du sol entraînant de mauvaises conditions physiques.

En raison de la multiplicité de ces facteurs, il est peu probable qu'on puisse déterminer les teneurs critiques en sodium échangeable pour une plante donnée.

Il semble que les effets des sels sur certaines plantes pourraient bien être liés à l'activité des systèmes d'enzymes.

DISCUSSION

A. R. **Kamaliddin.** With respect to the effect of exchangeable sodium on plant growth, does the present work show a more systematic correlation when the exchangeable sodium is expressed as ml./100 gm. of soil or when expressed as percentage exchangeable sodium of the total absorbed cations?

H. B. **Peterson.** The percentage of exchangeable sodium is much superior. It enables us to make comparisons between soils of very different exchange capacities.

M. M. **El-Gabaly.** Have there been any experiments on the effect of sodium and calcium on plants other than barley? Our experiments show that this effect is the reverse for peas.

H. B. **Peterson.** Barley is probably an example of an exception. Our experiences with clover were not the same. No effect on the growth of clover was noted when the proportions of calcium and sodium chlorides were varied at any given osmotic concentration.

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STUDIES ON SALT TOLERANCE AND SPECIFIC ION EFFECTS ON PLANTS

by
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NATURAL HALOPHYTES

The present study is aimed at finding out the salt tolerance range of some natural halophytes, and also the effect of salt content in the soil on the composition of these plants. The study was made in six localities in northern Egypt, and covered a wide range of salt content and textural differences.

The following determinations were made on soil samples collected: (a) conductivity of the saturated extract; (b) soluble Ca^{++}, Mg^{++} and Na^{+} in this extract; (c) base exchange capacity; (d) mechanical analysis; (e) *p*H of the 1 : 5 soil : water.

The roots and shoots were analysed separately for Ca, Mg, and Na.

Results

The results show that *Halocnemum strobilaceum* can exist under a widely varying conductivity, from 24 to 317 mmhos./cm.; the soluble sodium percentage may range from 69 to 84 per cent, *p*H from 7.9 to 8.5, and the soil texture from clay to sandy loam.

The sodium accumulated in the roots varied from 26 to 108 meq./100 gm. dry material, and in the shoots from 178 to 583 meq./100 gm. This sodium content in the plant may be higher or lower than in the soil depending upon the salinity of the medium.

Arthrocnemum glaucum has been found to exist under a conductivity ranging from 30 to 162 mmhos./cm., and in soils with a texture ranging from clays to sands. The sodium accumulated in the shoots ranged from 279 to 512 meq./100 gm., and in the roots from 57 to 118 meq./100 gm. of dry material. The amounts of sodium accumulating in the shoots of this plant seem to approach the value of 500 meq./100 gm., regardless of the concentration in the outside media.

Salicornia herbacea existed under a conductivity ranging from 24 to 200 mmhos./cm., and in relatively fine textured soil with a high water table. It accumulated sodium in amounts varying from 155.5 to 384.7 meq./100 gm. in the shoots.

Suaeda fruticosa existed under a conductivity ranging from 10 to 160 mmhos./cm.; the exchangeable sodium percentage was as high as 38.3, the soluble sodium ranged between 55 and 89 per cent, *p*H *from 7.6 to 9.4, and* the soil texture from clay to sand.

This plant accumulated sodium in the shoots in amounts ranging from 144 to 516 meq./100 gm., which may exceed the concentration in the medium. This plant can exist under both saline and saline-alkaline conditions.

Spergularia diandra existed under a conductivity ranging from 6.5 to 30 mmhos./cm.; *p*H ranged from 7.8 to 8.8, and soil texture from clay to silt loam. The sodium content in the plant was about 200 meq./100 gm. of dry material, regardless of the salt content in the soil. The plant has the ability to accumulate sodium in amounts exceeding those in the medium.

Inula crithmoides existed under a conductivity ranging from 3.2 to 45 mmhos./cm.; *p*H ranged from 8.0 to 9.4 and the soil had a relatively heavy texture; the soluble sodium percentage was low.

Conclusions

From the previous data we can say that *Halocnemum strobilaceum, Arthrocnemum glaucum, Salicornia herbacea,* and *Suaeda fruticosa* have the ability to survive under conditions of widely varying salinity, and can tolerate high salinity. *Inula crithmoides* and *Spergularia diandra* are definitely less tolerant. There seems to be no definite salt concentration range characteristic of a given plant species; instead, the conductivity ranges for the first four species overlap. This indicates that they can coexist under the same salinity condition. This wide range of salinities indicates that halophytic vegetation can grow well under both medium and high salinity, having the ability to adapt itself to the conditions of the environment.

It has been found that the first four species have the ability to accumulate large amounts of sodium in the shoots, as compared with the roots. This may explain their ability to withstand high concentrations of soluble sodium salts. Plants that accumulate sodium in the roots are less tolerant. This may suggest that the root is more sensitive to sodium accumulation, which may affect its metabolic activity. That may explain why roots are better indicators of salt and specific ion effects.

ECONOMIC CROPS

The salt tolerance of barley, wheat, clover and horse beans together with the effect of the salts in the medium on their composition have been studied under field conditions in certain selected areas in northern Egypt. The growth condition of the crop was recorded and both soil and plants collected were analysed, as mentioned previously.

Results

Barley. The results show that barley failed to grow when conductivity exceeded 27 mmhos./cm. and soluble sodium exceeded 65 per cent of the total. Growth of barley was poor with a conductivity range of 10–19 mmhos./cm. and soluble sodium greater than 50 per cent. Growth was fair with a conductivity range of 1–10 mmhos./cm. and a soluble sodium percentage of less than 50. Good growth of barley was observed when conductivity was less than 4.7 mmhos./cm.

Wheat. The results show that wheat failed to grow when conductivity was greater than 10.3 mmhos./cm. It showed poor growth with conductivity ranging from 5 to 10 mmhos./cm. Fair growth was observed with conductivity ranging from 3.5 to 5 mmhos./cm., when the soluble sodium percentage was less than 50. Good growth was observed with conductivity less than 3.5 mmhos./cm. and the soluble sodium less than 50 per cent. In one case it was observed that no growth took place at a conductivity of 3.55 mmhos./cm. The soluble sodium was found to be 82 per cent.

Clover. Showed no growth with conductivities higher than 13 mmhos./cm. when soluble sodium did not exceed 70 per cent of the total. Poor growth occurred over a wide range of conductivity (1.55–9.8), depending upon the soluble sodium percentage. Where the conductivity was less than 2 mmhos., the soluble sodium was as high as 85 per cent. Good growth was observed over a range of 1.12–4.7 mmhos./cm. when the soluble sodium was less than 40 per cent.

In one case growth failed at a conductivity of 2.8 mmhos./cm. Here soluble sodium was 96 per cent.

Horse beans. Showed no growth with conductivities higher than 15 mmhos./cm. when soluble sodium varied between 70 and 80 per cent. Very poor growth was observed with conductivities ranging from 3.8 to 9 mmhos. Fair growth took place with conductivity ranging from 2.5 to 6.8 mmhos. Good growth was observed with conductivities lower than 2.2 mmhos. and soluble sodium below 50 per cent. In one case beans failed to grow at a conductivity of 5 mmhos. In this case sodium was found to constitute 82 per cent of the total.

The chemical composition of plants

It was found that barley has the ability to accumulate sodium in large amounts. Plants showing good growth accumulated sodium in amounts ranging between 73 and 162 meq./100 gm., whereas plants showing poor growth contain sodium in excess of 200 meq./100 gm. It was noticed that while the sodium content in barley varied a great deal (74–262 meq./100 gm.), the ($Ca^{++} + Mg^{++}$) content varied relatively less (42–72 meq./100 gm.). This nutrient unbalance may be responsible for some of the effects of high salt content.

Wheat has less ability than barley to accumulate sodium, whereas clover falls between barley and wheat in that respect. Clover plants showing good growth contained 40–140 meq./100 gm. of sodium, those with fair growth contained from 124–146 meq./100 gm., and those showing poor growth contained more than 150 meq./100 gm.

Horse beans seem to have the least ability to accumulate sodium. Plants showing good growth contained from 31 to 60 meq./100 gm., whereas those showing poor growth contained from 129 to 185 meq./100 gm.

Conclusions

There seems to be no definite concentration of salt which is critical in retarding plant growth; instead, there is a conductivity range which may overlap for different crops and even for the same crop species. This indicates that factors other than the conductivity may modify this value. Of these factors the soluble sodium and exchangeable sodium percentages are important. If they are low, plants can withstand relatively higher concentrations of soluble salts.

Barley can withstand relatively higher concentrations of salts as well as a higher soluble sodium percentage; clover comes next. Wheat and beans on the other hand are more sensitive to salinity and sodium.

The analysis of the four plant species shows that plant composition can be altered by variations in the composition of the soil. This is particularly true as regards sodium. In setting standards for salt tolerance of crops therefore, both the conductivity and the soluble sodium percentage must be taken into consideration.

It appears from the present study that the principle of setting a salinity scale solely on the basis of the conductivity of the saturation extract heeds to be modified. Meanwhile, the value of 4 mmhos./cm. set as the limit between saline and non-saline soils seems to be rather high for the crops studied under the given growth conditions.

SPECIFIC EFFECTS OF ADSORBED IONS ON PLANT GROWTH

Considerable uncertainty still exists as to why certain ions in low concentration or in adsorbed form are toxic to certain plant species. This may be due to a number of factors including high *p*H, poor physical conditions of the medium and the specific effects of the ion. The present work deals with the specific effect of adsorbed Ca^{++}, Mg^{++} and Na^{+}—either in homoionic or biionic systems—on the growth and cationic accumulation in barley and beans plants.

Sand-amberlite mixtures were prepared containing 10 meq. of adsorbed ions per 300 meq. of mixture. Five degrees saturation were included for each of the three ion pairs: Na^{+}-Ca^{++}, Na^{++}-Mg^{++} and Ca^{++}-Mg^{++}.

Fifty germinating seeds were planted in each dish. The plants were left to grow for five weeks. At the end of the five-week period the plants were harvested, washed, photographed and the lengths of shoots and roots measured. The dry weight was determined and the plants were analysed for Ca, Mg, K and Na. The results are presented in figs. 1–5.

Conclusions

The results presented in fig. 1 on the specific effects of single adsorbed ions in different concentration on the growth of barley indicate that the specific effects exerted by adsorbed Ca^{++}, Mg^{++} and Na^{+} are a function of the ion itself, as well as of its concentration in the medium. Growth is reduced as the concentration of adsorbed ions *increases in the medium. Compared at equal concentration*, Mg^{++} and Na^{+} have been found to have more deleterious effects on the growth of barley than Ca^{++}. Within each series the effects were more pronounced with increasing concentration of adsorbed ions: at 70 meq. Ca^{++} slightly delayed germination, sodium almost prevented it, while magnesium inhibited it completely.

Recent work at our laboratory has shown that ions may effect the histogenesis of roots. This is reflected in the appearance of lignified xylem, and in the vacuolization of cortical cells. The ions brought about swelling of the gel framework of the cytoplasm to a varying extent.

The present study shows that any one cation depressed the growth of barley. A combination of any two, within a given range, stimulated growth. The stimulation range varied with the nature of the complementary ion and the measure used as an index of the effect. When calcium

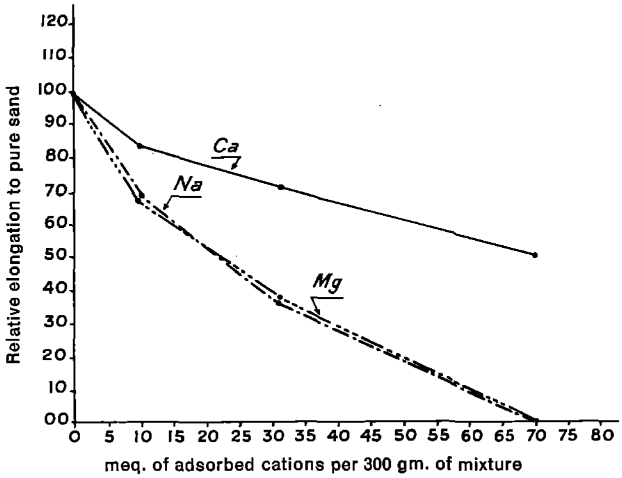

FIG. 1. Effect of concentration of adsorbed cations on the relative elongation of barley.

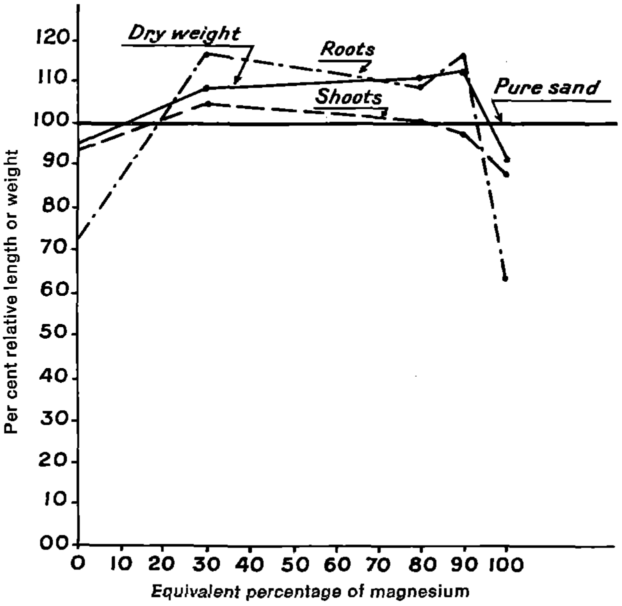

FIG. 2. Relative growth of barley in Ca-Mg systems.

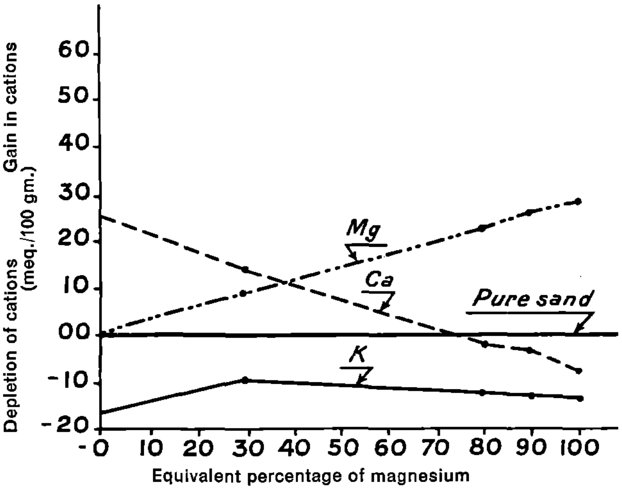

FIG. 3. Net gain or loss in cations in barley grown in Ca-Mg systems at different degrees of saturation.

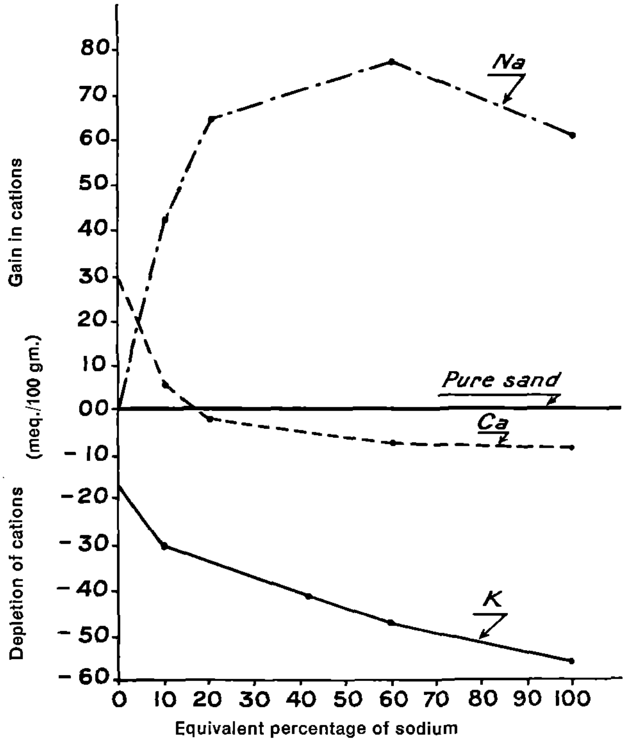

FIG. 4. Net gain or loss in cations in barley grown in Na-Ca systems of different degrees of saturation.

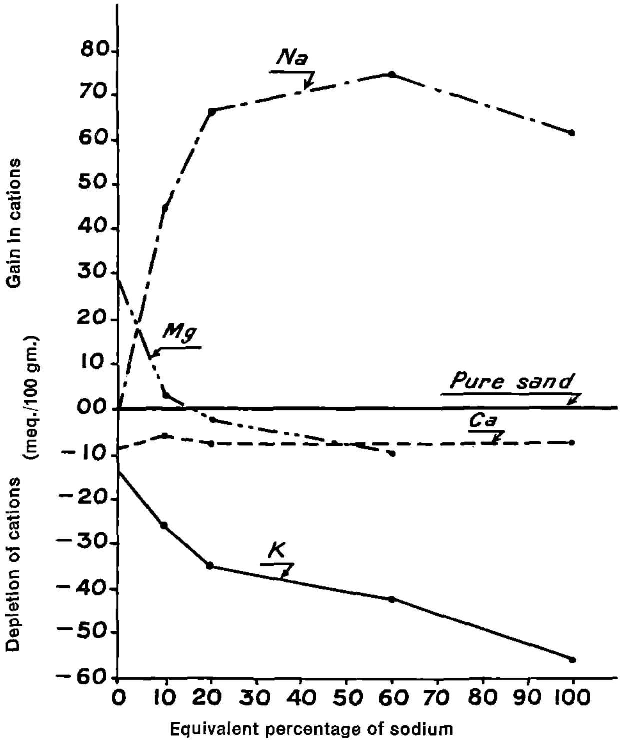

FIG. 5. Net gain or loss in cations in barley grown in Na-Mg systems at different degrees of saturation.

was the complementary ion with sodium, the stimulation range was wider than when Ca and Mg constituted the two adsorbed cations; this range was still greater than when sodium was one of the two cations adsorbed.

Since growth in the Ca-Na and Mg-Na systems is, within a given range, greater than in pure Ca or Mg systems, we can conclude that sodium, up to a given saturation percentage, may not in itself have a depressing effect on the growth of barley.

In both Ca-Na and Mg-Na systems Na taken up by roots increased with the increase in sodium saturation. In the meantime potassium suffered depletion. Barley lost Ca and Mg at relatively high degrees of Ca and Mg saturation.

The difference observed between Ca-Na or Mg-Na systems and pure Ca or pure Mg cannot be due to differences in Na uptake or loss of K, because the magnitude of absorption or depletion is more or less the same in both series.

The stimulation of growth in Ca-Na or Mg-Na systems as compared with pure Ca or pure Mg systems cannot be caused by a sufficient supply of Ca, Mg, and K, since their level in pure systems is higher. It may be due to a better balance among these nutrients. The specific effect of high Na saturation is the nutrient unbalance caused by differential uptake and depletion in nutrients.

The differential absorption of these three cations by barley depends on the activities of the ions both in the medium and on the root surface. The complementary ion effect shows itself in the relative uptake of the same ion.

In the Ca-Mg systems, barley gained Mg at all degrees of Mg saturation, and Ca at degrees of saturation of up to 28 per cent. The loss of K did not change greatly with the degree of Ca-Mg saturation.

As to the effect of different ions on the morphology of roots, we find that roots grown in pure Na and pure Mg systems are short, thick, and brown in colour, with a slight tendency to branching.

Those grown in Ca systems are long and fibrous, with normal branching and appearance.

EFFECT OF EXCHANGE CAPACITY OF MATERIAL ON GROWTH AND CHEMICAL COMPOSITION OF PEAS

Three materials—amberlite IR-H 100, bentonite and silty soil—were employed with exchange capacities of 170, 80, and 20 meq./100 gm. respectively. Na-Ca and Na-Mg systems were used, with 10, 20, 40 and 60 per cent sodium saturation in a concentration of 15 meq./300 gm. of material-sand mixture.

The number of seedlings germinating decreased with increased Na saturation in all systems; germination was greater in Na-Mg systems. In Ca-Na systems growth was best in soil, followed by montmorillonite; it was least in resins. The difference became more pronounced as Na saturation increased.

In Mg-Na systems, growth of peas was poor at all degrees of Na saturation and plants died shortly after germination.

The effect of exchange capacity was pronounced on peas in the Ca-Na systems. However, the nature of adsorbed ions may overshadow the capacity factor, as peas failed to grow with Na-Mg series at all degrees of Na saturation.

The capacity factor was investigated using two adsorbed ions Ca-Na and Mg-Na at 50 per cent saturation. Five concentrations, of 0, 5, 10, 30, 70 meq. per 300 gm. sand-resin mixture, were used. Fifty germinating barley seeds were planted in each pot.

The results are shown in figs. 6, 7 and 8.

The effect of increasing cation concentration on the length of shoots is not pronounced, especially in the Ca-Na series. However, the length of roots decreased with increasing cation concentration in both series.

Ca and Mg in the plants were depleted in all concentrations in both series. Ca suffered greater depletion than Mg which indicates that barley cannot take up any Ca from 50 per cent saturation. Na uptake varied little with concentration in the Na-Ca series but increased in the Na-Mg series.

The results show that increasing the concentration of adsorbed ions in the medium at 50 per cent saturation caused a deleterious effect on growth. We can therefore conclude that the specific effect exerted by Na, Mg or Ca is a function of the ion itself, as well as of its concentration in the medium.

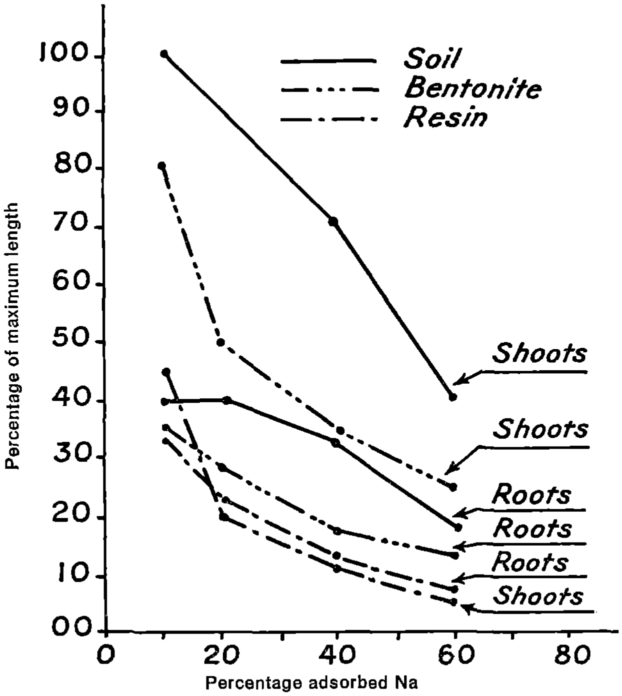

FIG. 6. Effect of exchange capacity of medium on the relative growth of barley grown in Ca-Na systems at different degrees of saturation.

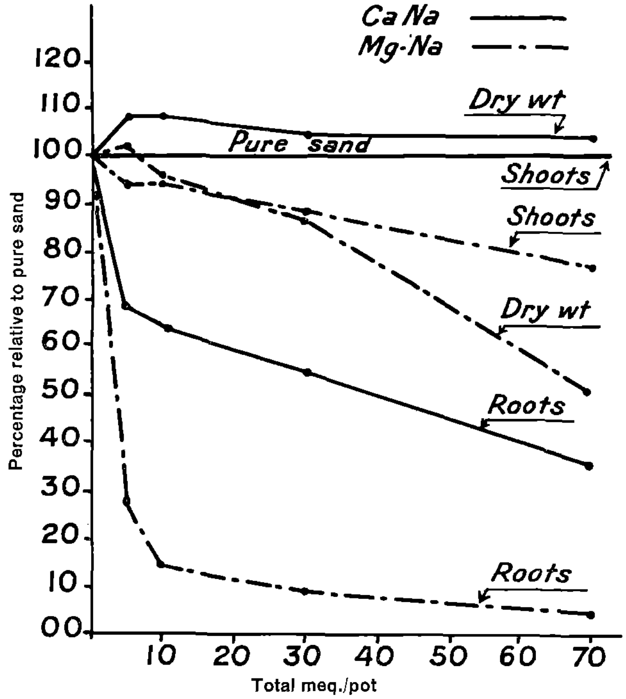

FIG. 7. Effect of concentration of adsorbed ions on the relative growth of barley in Ca-Na and Mg-Na systems.

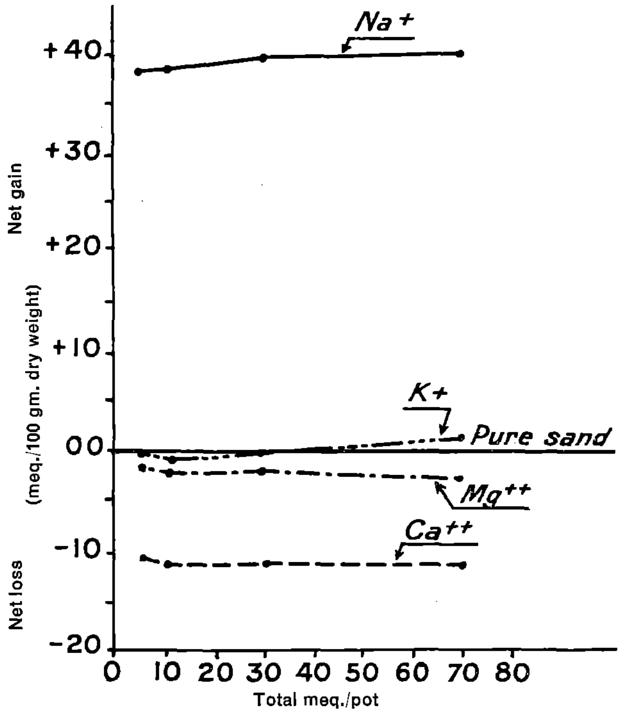

FIG. 8. Net gain or loss in cations in barley grown in Ca-Na systems at 50 per cent Na saturation but different concentrations.

RÉSUMÉ

Études sur la tolérance aux sels et les effets de certains ions sur les plantes (M. El-Gabaly)

La tolérance aux sels de six espèces naturelles d'halophytes a déjà été étudiée, ainsi que les effets sur leur composition de la concentration et la nature des sels présents dans leur milieu. On a ainsi découvert que les espèces *Halocnemum, Salicornia, Arthrocnemum* et *Suaeda* supportaient une concentration relativement forte de sels solubles, tandis qu'*Inula* et *Spergularia* semblaient moins tolérantes. Il n'existe pas apparemment de gamme de valeurs de la conductivité qui soit caractéristique de chaque espèce végétale. Au contraire, la conductivité indique que ces espèces coexistent dans les mêmes conditions de salinité.

Les valeurs maximum et minimum de la conductivité d'une espèce donnée varient d'un endroit à un autre, ce qui signifie peut-être que d'autres facteurs écologiques influent sur la tolérance aux sels de cette espèce.

La tolérance aux sels de l'orge, du blé, du trèfle et des haricots, ainsi que les effets des sels présents dans le sol sur la composition de ces plantes, ont été étudiés en plein champ.

Les effets spécifiques de Na^+ et de Ca^{++} adsorbés sur la croissance et l'accumulation cationique de pieds d'orge ont été étudiées sur des supports composés de résine et de sable.

On a également étudié l'effet sur les pois de l'augmentation du pourcentage de Na adsorbé en combinaison avec Ca ou Mg comme ions complémentaires. Les résultats semblent confirmer ceux qui ont été obtenus avec l'orge. Néanmoins, les pois semblent plus sensibles aux effets de Na et de Mg ainsi qu'à la carence de Ca.

DISCUSSION

C. A. **Bower**. Comment. In a recent sand culture experiment conducted at our laboratory, in which the interaction of total salt concentration and sodium statics in the presence and absence of an action exchanger (resin) were studied, the following results were obtained:

(1) When the exchanger was maintained in equilibrium with the solution phase by frequent irrigation, adsorbed sodium *per l.* had no effect on plant growth.

(2) Increasing the $Na/\sqrt{Ca + Mg}$ ratio of the solution phase decreased plant growth, but the effect was much less at high total salt concentrations than at low concentrations.

M. M. **El-Gabaly**. (1) The experiment reported by Bower on the use of frequent solution with resin is quite different from what has been reported by the author. The effect of adsorbed sodium in higher percentages is due to the unbalance between nutriments.

(2) The adsorption sodium ratio reported by Bower is a clear sign of the influence of sodium on plant. In all cases reported here soluble sodium percentages played an important part in retarding plant growth, particularly at low conductivity values.

G. **Aubert**. Les résultats présentés dans cette communication sont tout à fait intéressants et peuvent être très utiles. J'aimerais savoir quelle espèce de trèfle a été utilisée dans ce travail.

Par ailleurs, dans la 3e partie de sa communication, le professeur El-Gabaly paraît défendre l'idée que la proportion de Na échangeable permettant de définir les sols à alcalis devrait être choisie d'après les réactions à ces sols d'une plante comme l'orge. Pour nous, pédologues, c'est essentiellement d'après l'action de Na sur les propriétés physiques du sol que cette définition doit être établie; c'est seulement ensuite que nous étudierons leur effet possible sur les plantes.

M. M. **El-Gabaly**. The answer to the first question is that the clover used in this study is "Egyptian Berseem" or *Trifolum alexandrinum*. As to the second question, the studies reported were carried out in resin-sand mixture to overcome the effect of chafes on the physical properties mentioned by Professor Aubert. From a purely nutritional point of view we can say that adsorbed sodium, up to a certain percentage, depending upon the complementary ion, has a stimulating effect on plant growth.

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BORON TOXICITY AND PLANT GROWTH

by

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INTRODUCTION

In the early 1920's it was realized that boron is one of the essential nutrients for plants, although only needed in very small quantities. Boron may be found in soil, irrigation water, and ground-water. The quantities of boron vary from one area to another; soils deficient in boron cause a serious disease in plants. Addition of boron to the deficient soil is practised to meet the need of such plants. In Iraq there is no problem of boron deficiency, since boron is present in both the irrigation water and the soil [6].[1]

High concentrations of boron, whether in the soil or in irrigation waters, will result in injury to plants [1, 2, 3, 9]. Soils with excessive boron have to be reclaimed before any agricultural development can be undertaken. Leaching with large quantities of water usually results in the removal of excessive boron or its reduction to a level tolerable to most plants [8, 9].

The only mention of boron in the Old World was by Grillot [4], and no detailed study was made before the work of Kamaliddin and Kadaw [6]. The present study deals with the toxicity of boron to some Iraqi crops during germination and the later stages of their development. Boron toxicity was investigated using soil, sand culture, and solution culture.

Boron status in the soils and waters of Iraq

The soils and waters of Iraq were not investigated for boron content until 1956, when new agricultural projects were under study in the different parts of the country. Since most of these areas were under arid and semi-arid conditions and the soils were highly saline and alkali, it was thought that tests for boron content in the soils and waters were essential. Soil and water samples were collected by individuals and consulting firms working with soils in Iraq. The samples were analysed for boron by Kamaliddin and Kadaw [6]. They used the quinalizarin method for the chemical determination. They found that most Iraqi soils have a boron range of 0.1–0.5 ppm. in the saturation extract; the next largest range was 0.6–1 ppm. boron. Very few soils were found to contain 5 ppm. boron or higher. The maximum value found in southern Iraq was 12 ppm. boron. Generally speaking soils deficient in boron are very rare in Iraq.

Surface water of the Tigris, Euphrates and Shatt-al-Arab rivers, irrigation canals and marsh water have been found to have boron in the range of 0.1–0.8 ppm., but most of the waters analysed have 0.3–0.5 ppm. boron [6]. Ground-waters in central and southern Iraq have a boron content higher than 1.0 ppm., reaching 20 ppm. in some locations.

Soils of Iraq *inter alia* have about 30 per cent lime and variable quantities of gypsum, and a *p*H of 7.3–8.3.

Plant response to boron

Since the problem of boron deficiency does not seem to be a critical one in Iraq we shall consider here the problem of boron toxicity only. Excessive boron in the soil or the growth medium will result in absorption of boron by the plants, and hence sickly-looking crops. The toxicity symptoms due to excessive boron are characterized by burning of the edges of the leaves, with chlorosis near the marginal areas. In some cases the burned areas may be found extending inwards from the margins. Radicles of green-gram curled and twisted in the presence of high boron concentrations.

Different plant species vary in their tolerance to boron toxicity; some species are very susceptible while others are quite tolerant. Eaton [3], using 50 different species grown in sand culture, classified his plants according to their tolerance to boron into three groups: (a) boron-sensitive plants; (b) boron-semi-tolerant plants; (c) boron-tolerant plants. The degree of tolerance was estimated by dividing the average weight of plants in the sand culture with 1, 5, 10, 15 ppm. boron by the weight

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[1] The figures in brackets refer to the bibliography on page 179.

of plants grown in culture with trace boron, and multiplying this value by 100. The boron-sensitive plants have values below 50, while the boron-semi-tolerant plants have values between 50 and 100, and the boron-tolerant plants have values above 100.

It has been established in the United States [5] that waters with 0.67 ppm. boron may be toxic to the sensitive crops, and even the most tolerant plants are injured if the irrigation water contains 2–3 ppm. Soil containing 0.7–1.5 ppm. boron is considered within the safe limit for most crops [9].

Purpose of the present work

Soil conditions and the climate of Iraq are different from those of other countries where a great deal of work has been done on boron toxicity. The soil of the alluvial plain of central and southern Iraq has 30 per cent or more lime, with high *p*H values. Gypsum is also present in variable quantities in different parts of the country. The annual precipitation is low, the temperature is high and the relative humidity is low in the summer. Because of these conditions, evaporation is high. This high evaporation will result in a continuous increase of boron in the soil.

It was thought desirable to test boron toxicity on Iraqi crops under the local conditions, and then to compare the findings with those obtained elsewhere.

EXPERIMENTAL RESULTS

Experiments with soil

Since soils rich in boron are also high in salinity, and frequently in exchangeable sodium, the two causing injuries to plants, a non-saline, non-alkali soil was chosen for boron toxicity experiments. Plants were grown in this soil (silt clay loam) in pots and irrigated with borated water of different concentrations of boric acid every three days. Cotton, sesame, green-gram, and okra were used. The irrigation was carried out by adding sufficient water to bring the soil to field capacity in order not to leach the boron from the soil. The concentrations of boron solutions used were: 0.5, 1, 1.5, 2, 4, 5 and 10 ppm. boron. The experiment was carried out for two months, then repeated, but no toxicity symptoms were noticed. Other experiments using wheat and barley were conducted; large tin cans were employed and the soil was brought to field capacity with borated water of different concentrations before seed germination. Only negative results were obtained.

Experiments with sand culture

Clay pots and tin cans were used in these experiments; wheat, barley, cotton and sesame were used as experimental plants. Nutrient solutions with certain concentrations of boric acid were used for daily irrigation. Leaching was prevented in these experiments in order to allow all the boron to be available to the plants. The results of these experiments were similar to those of the soil, where no boron toxicity was observed.

Because of the negative results obtained with soil and sand culture, the following experiments were conducted to see the effect of boron on seed germination. The failure of plants to respond to the added boron in these experiments is explained later.

Seed germination experiments

Grains and seeds of wheat (Ajeeba), barley (local), green-gram and sesame were used extensively in these experiments in order to find the effect of boron on seed germination. The germination tests consisted in placing 100 seeds on filter paper in two Petri dishes, moistened with boron solutions of different concentrations. The rate of seed germination and the growth of radicles, coleoptiles or shoots were compared with a control set, where the seeds were moistened with distilled water.

The percentage of seed germination was not affected even when 200 ppm. boron was used. Seeds germinated in solutions with high boron content had the same percentages as seeds germinated in water. The effect of boron was noticeable in the growth of radicle or shoot. An example for this is presented in Table 1 for sesame seeds germinated in 0, 2, 4, 6, 10, 15, 20, and 40 ppm. boron. It can be seen that the growth of both radicle and shoots was reduced slightly with the increase in boron concentration.

TABLE 1. Average length of 20 sesame seedlings in centimetres; seeds germinated in boron solutions of different concentrations

Boron concentration in ppm.	Radicle measurements		Shoot measurements	
	24 hours	48 hours	72 hours	120 hours
0	0.27	0.56	2.64	2.92
2	0.27	0.51	2.51	2.77
4	0.24	0.48	2.39	2.60
6	0.21	0.43	2.31	2.42
10	0.20	0.38	2.20	2.24
15	0.18	0.34	2.06	2.08
20	0.15	0.31	1.96	2.00
40	0.14	0.28	1.91	1.94

Solution culture experiments

Seedlings germinated in special boron solutions were transferred to litre jars filled with a complete nutrient solution with all the major and minor nutrients—only boron was varied. The range used in one set of experiments was from 2 to 40 ppm. boron; in another set of experiments a narrower range of boron was used, i.e. 0.2–2.5 ppm. boron.

The solution culture experiments were carried out under controlled temperature (i.e. 27–30° C.) and light intensity. Either 6 or 12 plants were used per treatment.

Measurements of the length of plants were taken regularly and toxicity symptoms were observed daily.

The results of these experiments have shown that boron toxicity is not very evident in the early stages of plant development (fig. 1). The data on wheat growth in different boron solutions are presented in fig. 1. The coleoptile growth of the seedlings grown in a no-boron solution or in 40 ppm. boron are not significantly different, but the growth of the wheat plant at the 17th day was quite conspicuous and the difference in length of the control and the 40-ppm.-boron plants is evident. Boron toxicity was observed in green-gram, sesame, wheat and barley when the plants were grown in solutions of from 2 to 40 ppm. boron. The injury was very severe with the higher concentrations of boron. It can be seen from fig. 1 that the growth of plants grown in 20 or 40 ppm. boron was not only reduced, but also the rate of growth was lower with the increase of time.

Plants grown in the low range of boron (0–2.5 ppm.) were found to exhibit some toxicity symptoms. The toxicity limit was 0.8 ppm. boron in the solution culture. Plants were injured when boron was higher than 0.8 ppm. The difference in height between the control and the 2-ppm.-boron plants was not very great (fig. 2), nor did it show further suppression of growth with time, as was found with boron concentrations higher than 2 ppm. (fig. 1).

CONCLUSIONS

Chemical analyses of soils and water in Iraq have shown that boron is present in water and in high concentrations in some soils [6]. Rapid evaporation of water usually results in continuous increase in the boron content of the soil. High levels of boron cause plant injury and hence the removal of boron by leaching is necessary. Since the soils and environmental conditions are different in Iraq from other countries, it was thought necessary to find the toxicity limits of boron for Iraqi crops.

Growth and germination tests have revealed that high concentrations of boron do not seem to affect seed germination or the early stages of plant development. Later stages of growth are affected with 2 ppm. boron or higher. This finding may be considered of practical value where some boron-tolerant crops can be started during the reclamation of soils high in boron. Leaching with one metre of water removes most of the harmful salts, but only part of the boron [6, 8, 9]. Further irrigation will

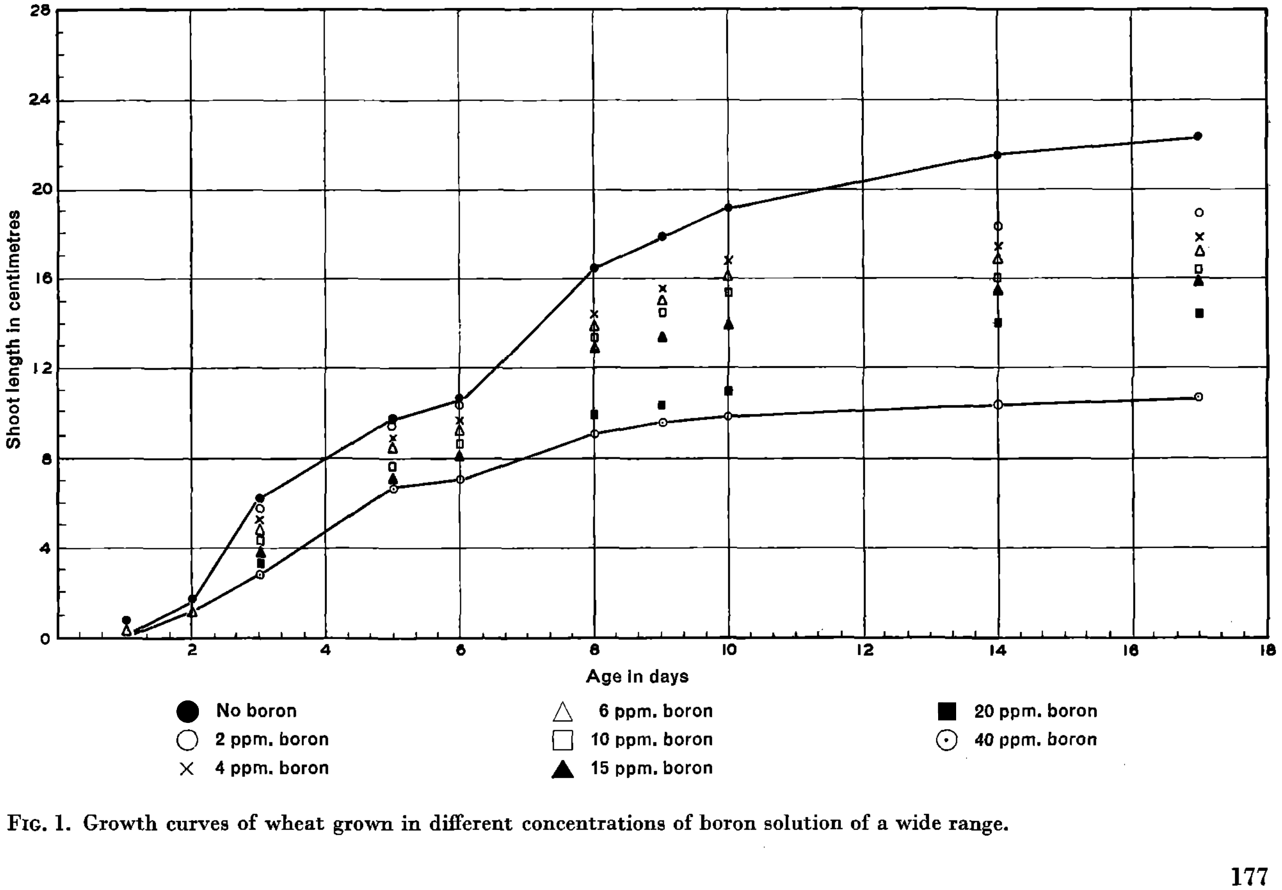

FIG. 1. Growth curves of wheat grown in different concentrations of boron solution of a wide range.

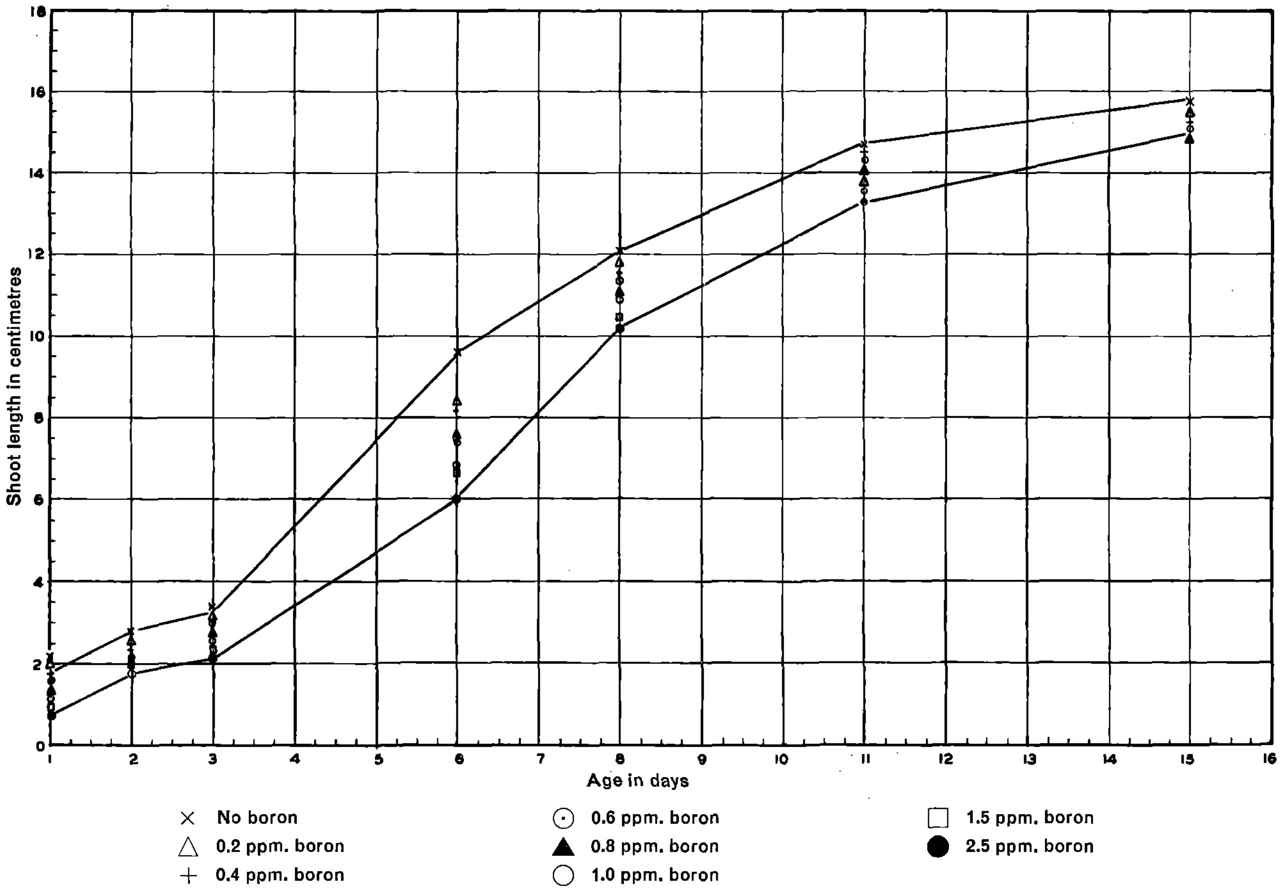

FIG. 2. Growth curves of green-gram grown in a narrow range of boron concentrations; the highest concentration used is 2.5 ppm. boron.

remove the other quantities of the boron, and the boron-tolerant crops will absorb whatever boron is left in the soil. Eaton [3] has shown that the accumulation of boron in plant tissue may range from 50 to 200 times the concentration of the external solution. From the present solution culture experiments it was found that absorption of boron is quite rapid.

The negative results obtained from experiments with soil and sand can be explained in terms of the unavailability of boron to plants and the consequent absence of absorption or injuries, even in the presence of high concentrations of boron. Eaton and Wilcox [9] have indicated that boron is fixed on soil particles. We have indicated earlier that the soils of Iraq have 30 per cent calcium carbonate or more. The presence of lime is thought by Berger, Reeve, Shive and other workers [7] to fix boron and make it unavailable to plants. The soil and sand used in the experiment mentioned were silt clay loam and loamy sand respectively; both contained lime. The problem of boron of the Iraqi soils needs further investigation.

The toxicity limit of boron for the four Iraqi crop species mentioned here was 0.8 ppm. boron in the solution culture, which is similar to that found elsewhere [1, 2, 9]. A knowledge of the response of these crops to different boron concentrations during germination and later stages of plant development will facilitate further soil experiments.

ACKNOWLEDGEMENTS

Grateful acknowledgement is due to Dr. A. R. Kamaliddin and his co-workers of the Irrigation and Drainage Laboratory, College of Engineering, Baghdad, for the use of their unpublished data on boron content in the soils and waters of Iraq. Thanks are also due to Mr. F. Bazaz and Mr. A. Shakir for their assistance in the germination and growth tests.

RÉSUMÉ

Le bore et la croissance des plantes (A. K. Khudairi)

L'effet nocif d'un excédent de bore dans les eaux d'irrigation ou dans le sol a fait l'objet de recherches effectuées en Irak avec des plantes cultivées sur sol, sur solutions ou sur sable. On a constaté que les limites de toxicité en ce qui concerne ces plantes correspondent à celles que signalent d'autres travaux.

On a également constaté que la formation des parois cellulaires ainsi que le développement de la plante ne souffrent pas de la présence de pourcentages élevés de bore dans le sol. Ainsi il n'est pas nécessaire, pour défricher, d'éliminer complètement le bore par lessivage du terrain, lorsqu'il n'exerce pas d'influence nuisible sur la formation des parois cellulaires.

DISCUSSION

M. L. DEWAN. The author has quoted several figures of boron content in Iraqi soils analysed by Dr. Kamaliddin. At what depth were the soil samples taken? Was there any difference in boron contents at various depths and could any generalization be made on boron content as related to depth or to any soil characteristic changing with depth (including effect of ground-water table on boron content of the soils in contact with the ground-water)?

A. K. KHUDAIRI. The soil samples were collected from different depths; from the surface down to 2 metres. Boron content varies from one depth to another, but in general there is more boron near the surface and boron decreases with depth.

R. D. ASANA. Was pure sand used in your sand culture experiments? If so, how would you account for the absence of any effect of high concentrations of boron on your plants?

A. K. KHUDAIRI. This was not pure sand; it contained some silt and had a texture of loamy sand.

G. REPP. As mentioned, a higher lime content of the soil decreases the poisonous effect of boron, because the boron is fixed in a form in which it is not available for the plant.

It would be of interest to investigate: (a) boron effects in the same climatic conditions in a soil very poor in or free of lime; (b) the effects of additional fertilizing with lime on the boron damage. Since leaching of boron needs a lot of water, the possibility of decreasing the damage by lime or lime-containing fertilizers would be of great practical interest.

A. K. KHUDAIRI. This is what we intend to do. The application of lime is practised in some parts of the world when the soil is acid, but with alkaline soil the addition of lime may cause some difficulties.

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PHYSIOLOGICAL PROBLEMS CONCERNING CROP PRODUCTION UNDER SALINE CONDITIONS IN INDIA

by
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HOW SALINITY AFFECTS PLANT GROWTH

Plant growth is adversely affected by soil salinity due to (a) what is called total soil moisture stress, which is a combined effect of soil moisture tension and increase in the osmotic pressure of the soil solution, and (b) toxicity of specific ions. It may be generalized that high concentrations of potassium, calcium, magnesium, chloride, sulphate, carbonate and nitrate ions prove injurious. Plant growth appears to be much more affected by exchangeable sodium in the soil than by an equal amount in true solution.

REVIEW OF WORK CARRIED OUT IN INDIA

Investigations carried out so far in India have been more or less of an applied nature and the results of these are briefly summarized below.

Alam [1][1] found that as a result of soaking paddy seeds in 0.1 per cent solution of sodium chloride, the seedlings could tolerate 0.35 per cent salt content in the soil. Seeds from these plants could germinate in a stronger solution than those of the preceding generation and salt tolerance could thus be built up gradually.

Parija [7] also found that seedlings from seeds soaked in 1.7 per cent solution could successfully grow in pots irrigated with salt solution. It was further observed that salt-tolerant varieties of paddy accumulated a greater concentration of salt in the tissues than susceptible varieties. The chloride content of grains of salt-tolerant varieties did not rise with saline irrigation of pot-culture, while it did rise in non-resistant varieties. The exodermis layer of roots in the salt-resistant varieties was considerably suberized and some suberin formation occurred in non-resistant varieties under saline conditions.

It was also observed at this institute some 12 years ago[2] that wheat grain, soaked in sodium chloride solution before sowing, germinated better than untreated seed in soil containing 0.2 per cent sodium chloride.

Professor R. H. Dastur's investigations in the Punjab on the cotton crop amply illustrate how suitable cultural practices can counter the adverse effect of saline subsoil. The Punjab American cotton failed for the first time in 1919 after showing symptoms such as yellowing and premature shedding of leaves, incomplete opening of bolls with poorly developed seeds and lint. These failures recurred partially or completely in several subsequent years until 1932. Dastur took up the investigation of this problem in 1935 and continued it for the next seven years. Details of this investigation are available in his monograph [2]. He observed during 1935 and 1936 that the symptoms of *tirak*, or "bad opening of bolls", described above, were present even though these two years proved to be normal, and deduced that some adverse soil condition was involved. Soil analysis indicated that two soil types were associated with *tirak:* (a) light sandy soil deficient in nitrogen, and (b) soil with a relatively large quantity of sodium salts or sodium clay, or both together, at a depth of about 3 ft. and below. A pronounced drooping of leaves was observed during September-October (fruiting period) in the second type of soil, the leaves remaining drooping throughout the day for about a week after each irrigation. The leaves turned dark and dull, losing their green lustre, and dropped off prematurely. It appeared that *tirak* was caused by physiological drought brought about by the presence of a saline subsoil at the fruiting stage.

To test the above-mentioned theory sodium salts were injected into the plants and the salinity of the subsoil was increased. Injections of salts did not affect the opening of bolls, although occasionally injections at the bolling stage killed the plants and the bolls cracked when still immature. This effect was not the same as *tirak.* Field experiments in which salts such as NaCl, Na_2CO_3 and $NaHCO_3$ were added in appropriate quantities to the subsoil gave illuminating results. NaCl depressed both vegetative growth and yield and induced immaturity in seeds and bad opening of bolls. Carbonate decreased

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[1] The figures in brackets refer to the bibliography on page 183.

[2] Indian Agricultural Research Institute, New Delhi, *Annual Report 1946–47.*

vegetative growth but stimulated fruiting when in low concentrations. Bicarbonate, in high concentrations, appeared to decrease the depressing effect on yield of high concentrations of NaCl.

Chemical analysis revealed a low potash content in the carpels of *tirak*-affected bolls, but fertilization of the soil with potash did not correct this disorder.

More frequent irrigation during September-October did help, but this did not appear to be a practical remedy because of the increased demand for irrigation water for the preparation for winter sowings. Late sowing (about the middle of June in place of middle of May) was therefore tried with a view to reducing plant size—and hence the demand for water—and it was found that bolls opened normally with mature seeds and good lint. The decrease in boll number owing to reduced plant size was counterbalanced by adopting a closer spacing. Thus late sowing (mid-June) combined with closer spacing turned out to be the practical remedy for this malady.

The question why this malady occurred in an epidemic form during some years was also considered. On analysis of the weather data it was discovered that the years in which crop failures occurred were characterized by short spells of intense hot and dry weather during September-October, and it appeared that this desiccating weather, combined with subsoil salinity, aggravated *tirak* and brought about crop failure.

Rao and his collaborators, at the Agra College, Agra, have taken up in recent years the study of the effect of different salts of sodium on the metabolism and growth of crop plants.

CONSIDERATIONS FOR FURTHER WORK

It may be noted that *desi* (indigenous) cottons did not show symptoms of *tirak*, indicating thereby their resistance to subsoil salinity [2]. Varietal differences in resistance to salinity have been observed in other crops. If the causes of this differential varietal response could be ascertained, a useful clue to an understanding of the basis of salt tolerance could be obtained. It would then be possible to work out suitable indices of salt resistance and thus aid breeding of salt-resistant varieties. Variation in tolerance of salinity with age must also be borne in mind. There is evidence to show that some species are relatively more salt-resistant in the early stages and others in the later stages, thus indicating the inapplicability of a single test to different species. Again, as far as crop plants are concerned the yield factor must not be lost sight of, for the ultimate agronomic criterion is yield. It would seem more profitable, from this point of view, to consider in the first instance those characters which are in direct line of yield, especially for such crops as are susceptible in later stages. A comparative growth analysis, combined with chemical analysis of tissues of such plants under normal and saline conditions, should, therefore, prove useful.

Germination and the establishment of a good stand are critical factors in crop production, particularly when the surface soil layers are saline. A noteworthy point in this connexion is the absence of correlation between salt tolerance at germination and during later phases of growth. Hayward [5] quotes a number of instances to illustrate this point. Considerable variation in the germination capacity of seeds of different crops, under saline conditions, has been reported, but little information is available regarding varietal differences in this respect. It would also seem useful to explore the possibilities of improving the germination capacity of seeds by pre-sowing salt treatment, as some success has been claimed by Alam [1], Parija [7] and Kursanov [6].

RÉSUMÉ

Les problèmes physiologiques relatifs à la production agricole dans les terres salines de l'Inde (R. D. Asana)

La croissance des végétaux est contrariée par la salinité, en raison de la succion totale du sol et de la toxicité de certains ions. On a constaté que le riz de semence trempé dans une solution de chlorure de sodium donne des plantes capables de supporter un sol plus fortement salé. Les graines produites par ces plantes arrivent elles-mêmes à germer dans une solution encore plus concentrée, si bien qu'on peut ainsi augmenter progressivement la tolérance au sel.

Au Pendjab, la culture du coton américain a d'abord échoué à cause du *tirak* (déhiscence défectueuse des capsules); les recherches consacrées à cette maladie ont montré qu'elle était due à une déshydratation — elle-même imputable à la salinité du sous-sol — au stade de la fructification. En semant le coton plus tard (vers la mi-juin), on a obtenu des plantes plus petites, dont les besoins hydriques étaient moindres, et dont les capsules s'ouvraient normalement, libérant des graines mûres et un duvet de bonne qualité. Comme une plante de taille réduite porte moins de capsules, on a — pour compenser — planté plus serré.

Les cotons indigènes (*desi*) n'ont présenté aucun symptôme de *tirak*, montrant ainsi leur résistance à la salinité du sous-sol. Si l'on pouvait déterminer à quoi répondent ces différences de comportement, on obtiendrait de bons indices de résistance au sel. Vu l'importance du rendement, il serait également utile de procéder à une étude comparative de la croissance des plantes, combinée avec une analyse chimique de leurs tissus respectifs, en milieu normal et en milieu salin.

DISCUSSION

P. Simonneau. En Algérie les accidents observés pour le cotonnier (*Karnak* et *Dendérak*) sont les mêmes. Toutefois, la chute des feuilles n'intervient qu'au moment de la déhiscence incomplète des capsules, après une chute d'organes floraux s'élevant à 15–20%.

Dans les solontchaks sodo-calciques où sont pratiquées les cultures, la concentration saline optimum est enregistrée entre 10 et 40 cm de profondeur, en septembre, quand commencent les éclatements.

Pour remédier à ces accidents, nous avons adopté: *a*) un dispositif particulier d'aménagement du terrain: billons très hauts, espacés d'un mètre; le cotonnier évolue ainsi dans un milieu relativement assaini; *b*) une forte densité de plantation (130 000 pieds/ha) qui assure un rendement normal.

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SALT TOLERANCE OF VARIOUS VARIETIES OF AGRICULTURAL CROPS AT THE GERMINATION STAGE

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REVIEW OF LITERATURE

Early workers [5, 6, 11][1] studied the effect of high osmotic pressure of the soil solution on seed germination. Other workers [7, 8, 9, 12, 13] pursued the problem on similar lines, using soil and water as growing media. Shive [10] tested the seed germination of beans and corn in sand cultures with an osmotic pressure of 0.5 to 8.0 atm. Ayers and Hayward [4] studied the problem of seed germination of a number of crops in large culture plates; they maintained the soils at specified moisture percentages and salinity levels, used a definite number of seeds and kept the temperature of the plates at 70° F. Their data furnished information on the relative tolerance of salts by the germinating seeds. Ayers [2] noted that the effect of salinity in diminishing the emergence percentage was most severe at low levels of soil moisture, even though the soil was still above the permanent wilting percentage. He also found that the increased soil moisture stress was reflected in an increase in the emergence time and a decrease in the percentage of seeds germinated. He tested various varieties of barley under controlled conditions [3], but did not notice any significant salt tolerance amongst the varieties tested. Ahmad [1] examined a number of varieties of various crops for their salt tolerance, using different concentrations of NaCl. He used the method employed by Ayers and Hayward [4], except that the tests were conducted at room temperature.

MATERIALS AND METHODS

Two soils, a sandy loam and a loam, were selected, air-dried and passed through a 2 mm. sieve. These soils were analysed for particle size distribution, total soluble salts and chlorides. The field and the total water-holding capacities were also determined. The data are given in Table 1. Some 1,000-gm. samples of the soils were placed in galvanized iron trays measuring 6.5 × 8 in. at the bottom, 8 × 10 in. at the top and 2 in. in depth; the trays were coated with aluminium paint to prevent rusting. Requisite quantities of NaCl were added so that the final concentrations of NaCl were 0.03 (original soil), 0.1, 0.2, 0.3, 0.4, 0.5 and 0.6 per cent. Salt was added in solution, and the moisture levels were raised to 15, 30, 45, 60, 75 and 90 per cent of the total water-holding capacity by the addition of distilled water. The total number of treatments was 84. Actually somewhat more water than the calculated quantity was added and the moisture was allowed to evaporate till the moisture percentages reached the desired levels. The soils were stirred and each tray was sown to a known number of seeds of the different varieties of each crop. Daily weighings were made and the moisture deficits were made up by adding moisture in fine sprays with the help of a hand atomizer. As the seeds were quite near the soil surface, moisture, even in small percentages, was available to them. Daily observations on seed emergence were recorded and 20 days were allowed as a germination period. A seed was considered to have germinated when the plumule was 3 mm. high. The data collected are given in figs. 1–5 and Tables 2–6.

RESULTS AND CONCLUSIONS

Wheat

In the case of wheat, the results of varieties C591, C518, C228, C250 and C217 are given in figs. 1–5 respectively. At a moisture level equivalent to 90 per cent of the water-holding capacity of the soil, the germination percentages of the seeds are quite low, presumably owing to the replacement of soil air. The varieties C228 and C250 germinated up to 60 per cent with low soil salts. At the moisture level equivalent to 15 per cent of the water-holding capacity germination is adversely affected; it suffers especially when the NaCl concentration is above 0.2 per cent. With the soil moisture maintained at 30 per cent of the water-holding capacity, all varieties germinate

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[1] The figures in brackets refer to the bibliography on page 192.

TABLE 1. Chemical and mechanical composition of soils used

Soil textural class	Total soluble salts	NaCl	Field capacity	Total water-holding capacity	Coarse sand 2.0–0.2 mm.	Fine sand 0.2–0.02 mm.	Silt 0.02–0.002 mm.	Clay > 0.002 mm.
	%	%	%	%	%	%	%	%
Loam	0.144	0.031	18.44	34.31	3.03	46.55	30.92	19.36
Sandy loam	0.121	0.0236	11.37	22.63	6.71	62.69	26.22	4.38

TABLE 2. Percentage seed germination of maize varieties at different salt and moisture levels

NaCl concentrations	15% moisture			30% moisture			45% moisture			60% moisture			75% moisture		
	Hybd. 7	Hybd. 8	Hybd. 59	Hybd. 7	Hybd. 8	Hybd. 59	Hybd. 7	Hybd. 8	Hybd. 59	Hybd. 7	Hybd. 8	Hybd. 59	Hybd. 7	Hybd. 8	Hybd. 59
Control	40	40	60	100	100	100	100	100	100	100	90	100	100	100	100
0.1%	20	20	50	100	100	100	100	100	100	100	100	100	100	100	100
0.2%	—	10	—	100	60	90	100	100	100	100	90	100	80	100	100
0.3%	—	—	—	50	30	60	100	100	100	90	100	90	100	100	100
0.4%	—	—	—	—	—	50	100	60	100	90	100	80	70	80	80
0.5%	—	—	—	—	—	—	70	80	80	80	80	80	70	70	70
0.6%	—	—	—	—	—	—	50	70	50	60	50	80	50	60	60

TABLE 3. Percentage seed germination of barley varieties at different salt and moisture levels

NaCl concentrations	15% moisture		30% moisture		45% moisture		60% moisture		75% moisture	
	T5	C141	T5	C141	T5	C141	T5	C141	T5	C141
Control	—	—	100	100	100	100	100	100	100	100
0.1%	—	—	100	90	100	80	100	100	100	100
0.2%	—	—	100	95	100	100	100	100	100	100
0.3%	—	—	50	35	100	100	100	100	100	90
0.4%	—	—	20	5	100	90	100	100	85	55
0.5%	—	—	—	—	65	55	95	90	75	55
0.6%	—	—	—	—	30	10	60	50	65	50

TABLE 4. Percentage seed germination of gram varieties at different salt and moisture levels

NaCl concentrations	15% moisture		30% moisture		45% moisture		60% moisture		75% moisture	
	Pb. 7	C12/34	Pb. 7	C12/34	Pb. 7	C12/34	Pb. 7	C12/34	Pb. 7	C12/34
Control	—	—	90	100	100	100	100	100	100	100
0.1%	—	—	20	60	100	100	100	100	100	100
0.2%	—	—	—	—	40	60	90	70	100	100
0.3%	—	—	—	—	40	40	70	60	80	90
0.4%	—	—	—	—	10	20	40	30	60	70
0.5%	—	—	—	—	—	—	30	10	50	60
0.6%	—	—	—	—	—	—	—	—	40	10

TABLE 5. Percentage seed germinations of rice varieties at different salt and moisture levels

NaCl concentrations	15% moisture							30% moisture							45% moisture						
	Mushkan 7	Mushkan 41	Jhona 349	Malhar 346	Basmati 370	Palman 246	Sathra 278	Mushkan 7	Mushkan 41	Jhona 349	Malhar 346	Basmati 370	Palman 246	Sathra 278	Mushkan 7	Mushkan 41	Jhona 349	Malhar 346	Basmati 370	Palman 246	Sathra 278
Control	—	—	—	—	—	—	—	30	20	20	5	25	30	30	75	100	90	70	85	100	100
0.1%	—	—	—	—	—	—	—	20	5	—	—	15	—	30	85	55	100	100	100	100	100
0.2%	—	—	—	—	—	—	—	10	—	—	—	—	—	—	55	45	55	55	80	75	40
0.3%	—	—	—	—	—	—	—	—	—	—	—	—	—	—	45	45	—	—	60	20	—
0.4%	—	—	—	—	—	—	—	—	—	—	—	—	—	—	30	25	—	—	—	—	—
0.5%	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
0.6%	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

NaCl concentrations	60% moisture							75% moisture							90% moisture						
	Mushkan 7	Mushkan 41	Jhona 349	Malhar 346	Basmati 370	Palman 246	Sathra 278	Mushkan 7	Mushkan 41	Jhona 349	Malhar 346	Basmati 370	Palman 246	Sathra 278	Mushkan 7	Mushkan 41	Jhona 349	Malhar 346	Basmati 370	Palman 246	Sathra 278
Control	90	90	100	80	90	100	100	100	90	100	70	100	100	100	100	90	95	90	100	80	100
0.1%	100	100	100	100	100	100	100	100	80	95	95	100	100	100	100	85	100	70	100	100	100
0.2%	85	75	55	65	85	100	95	100	90	100	80	100	100	100	100	70	100	85	100	100	100
0.3%	100	65	30	45	90	85	100	100	100	70	65	90	100	100	100	85	90	85	100	100	100
0.4%	70	55	30	40	85	65	45	100	65	45	60	85	80	55	85	70	85	85	100	100	100
0.5%	20	15	20	20	70	10	5	95	35	25	15	65	55	55	35	45	65	40	45	60	60
0.6%	15	5	—	—	—	10	10	40	30	25	10	5	15	15	25	25	60	40	15	10	30

TABLE 6. Percentage seed germination of cotton varieties at different salt and moisture levels

NaCl concentrations	15% moisture									30% moisture									45% moisture				
	L.S.S.	4F	119S	124F	199F	39M	238F	268F	289F/43	L.S.S.	4F	119S	124F	199F	39M	238F	268F	289F/43	L.S.S.	4F	119S	124F	199F
Control	—	—	—	—	—	—	—	—	—	60	70	70	80	80	20	30	10	20	100	90	100	100	100
0.1%	—	—	—	—	—	—	—	—	—	40	60	50	50	60	20	20	—	10	100	100	100	100	100
0.2%	—	—	—	—	—	—	—	—	—	30	40	30	40	30	—	—	—	—	100	100	70	80	100
0.3%	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	50	60	40	60	60
0.4%	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	40	40	40	40	40
0.5%	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
0.6%	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

NaCl concentrations	45% moisture				60% moisture									75% moisture								
	39M	238F	268F	289F/43	L.S.S.	4F	119S	124F	199F	39M	238F	268F	289F/43	L.S.S.	4F	119S	124F	199F	39M	238F	268F	289F/43
Control	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.1%	60	100	90	80	100	100	100	100	100	100	100	100	100	100	100	90	100	90	100	100	100	100
0.2%	50	80	50	50	100	100	100	100	100	80	100	80	80	80	80	80	70	90	90	100	90	100
0.3%	20	40	20	20	60	60	70	70	80	40	70	40	60	60	70	60	60	60	70	100	80	90
0.4%	—	—	—	—	40	50	30	40	30	10	40	10	40	40	50	40	50	50	60	80	50	50
0.5%	—	—	—	—	30	30	20	20	10	—	10	—	30	30	40	30	30	30	30	50	30	30
0.6%	—	—	—	—	—	—	—	—	—	—	—	—	30	—	20	30	10	—	—	20	—	20

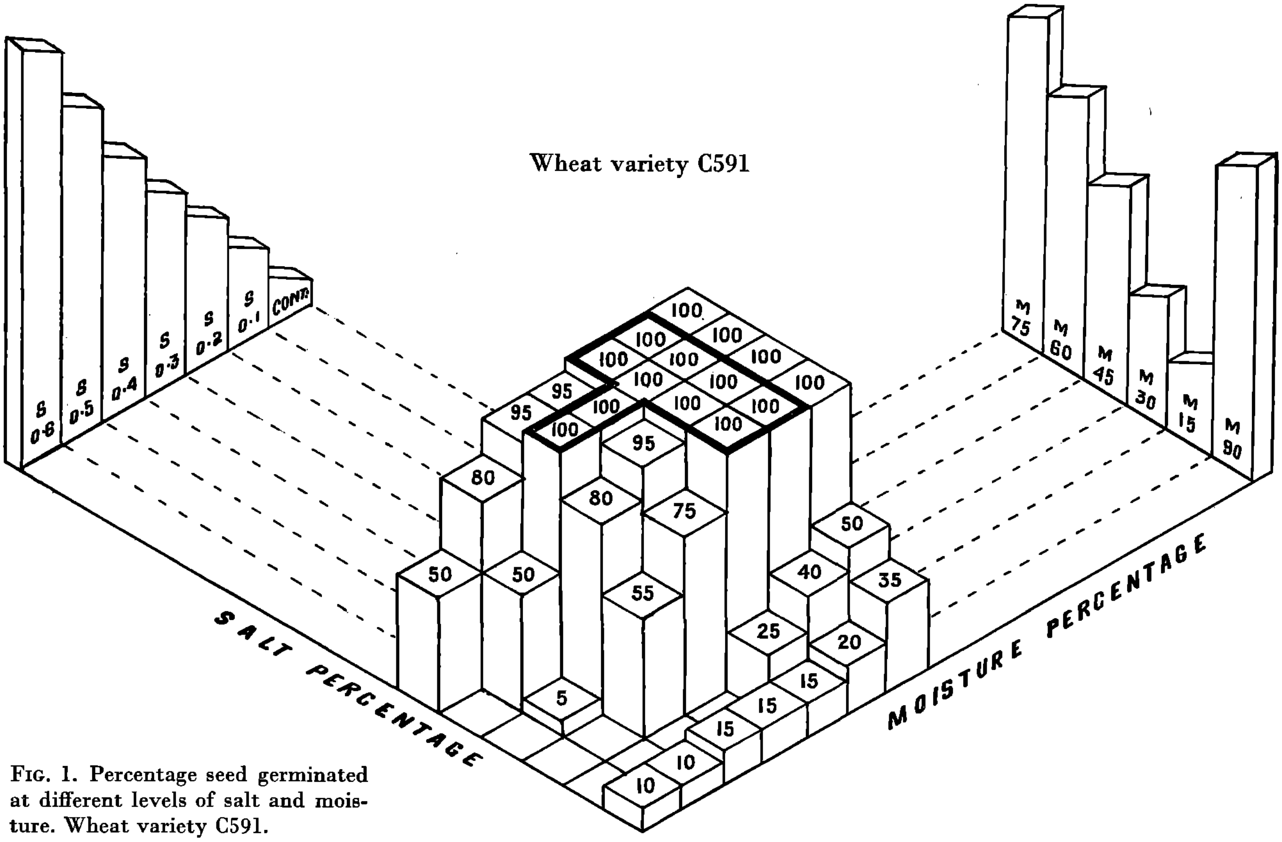

FIG. 1. Percentage seed germinated at different levels of salt and moisture. Wheat variety C591.

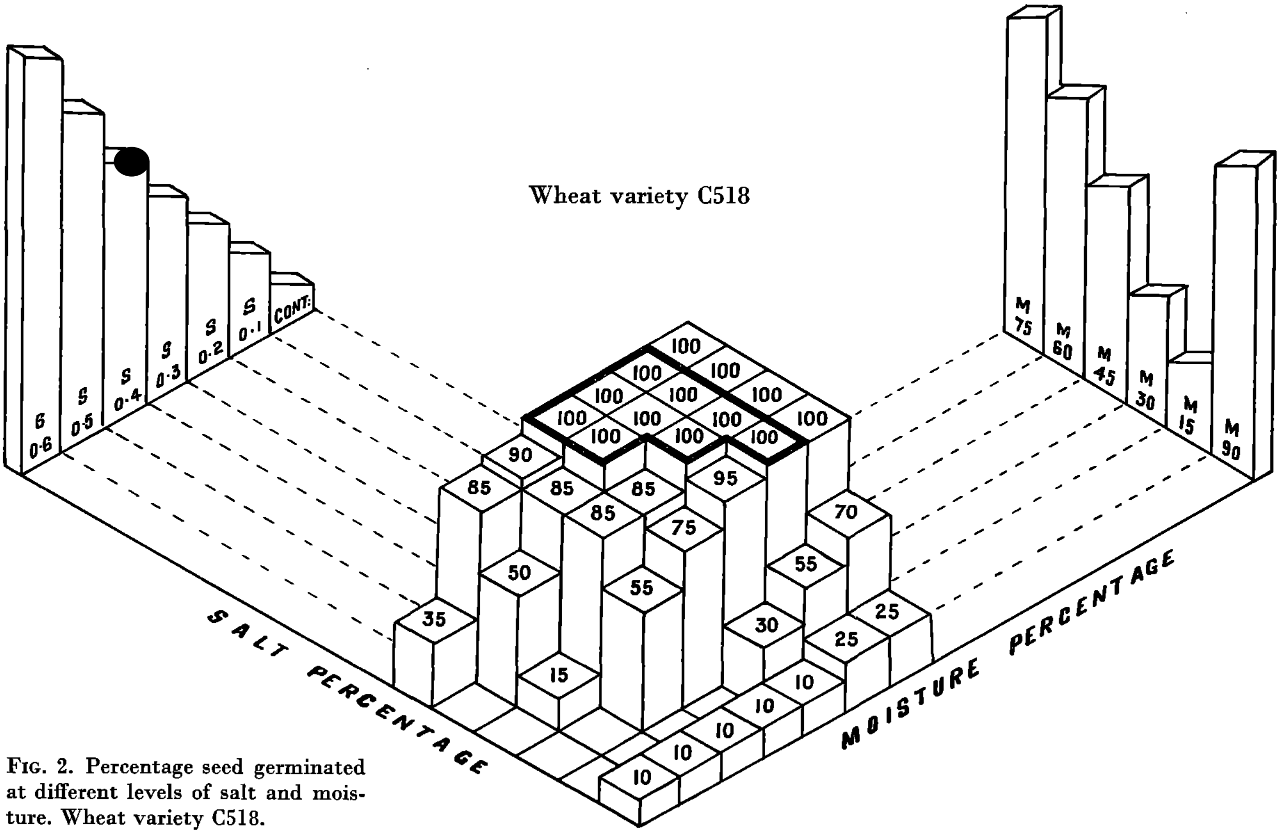

FIG. 2. Percentage seed germinated at different levels of salt and moisture. Wheat variety C518.

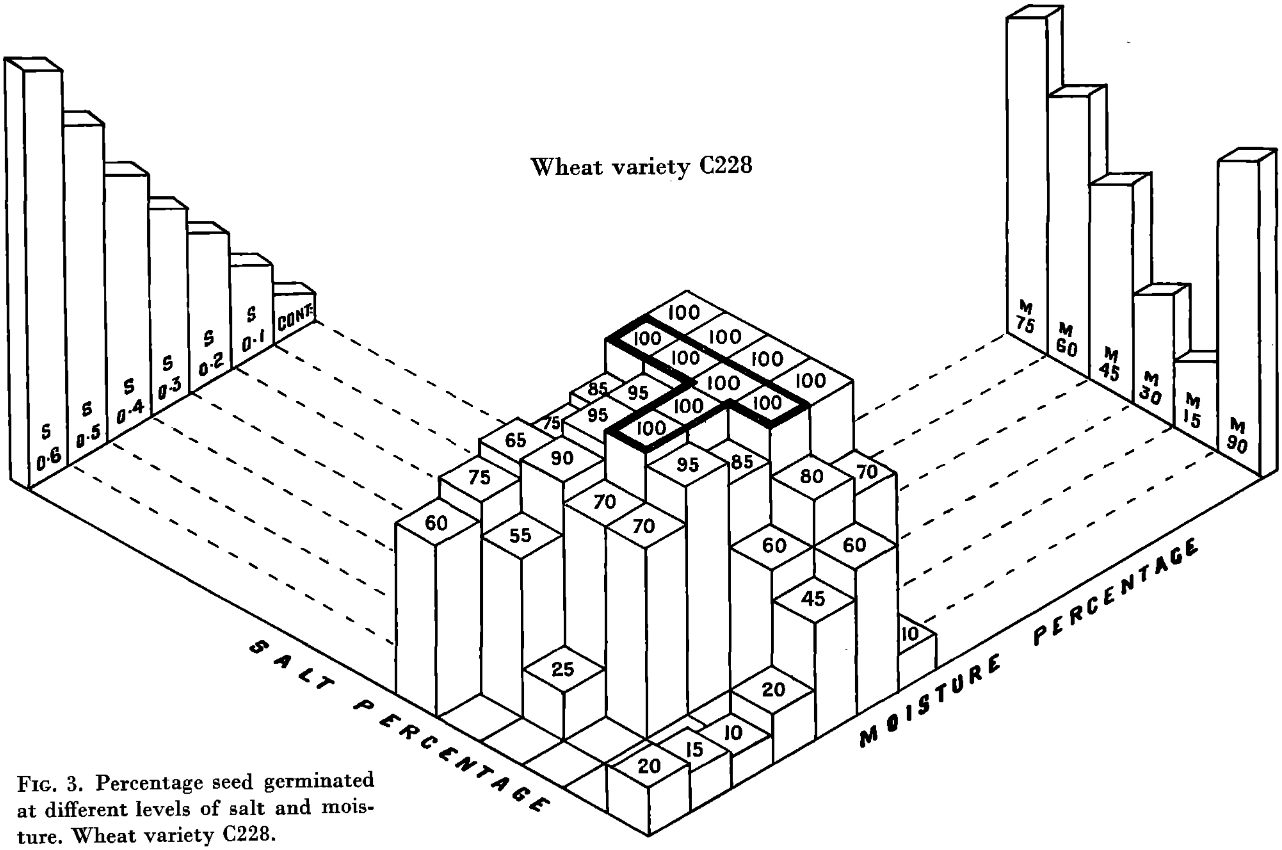

Fig. 3. Percentage seed germinated at different levels of salt and moisture. Wheat variety C228.

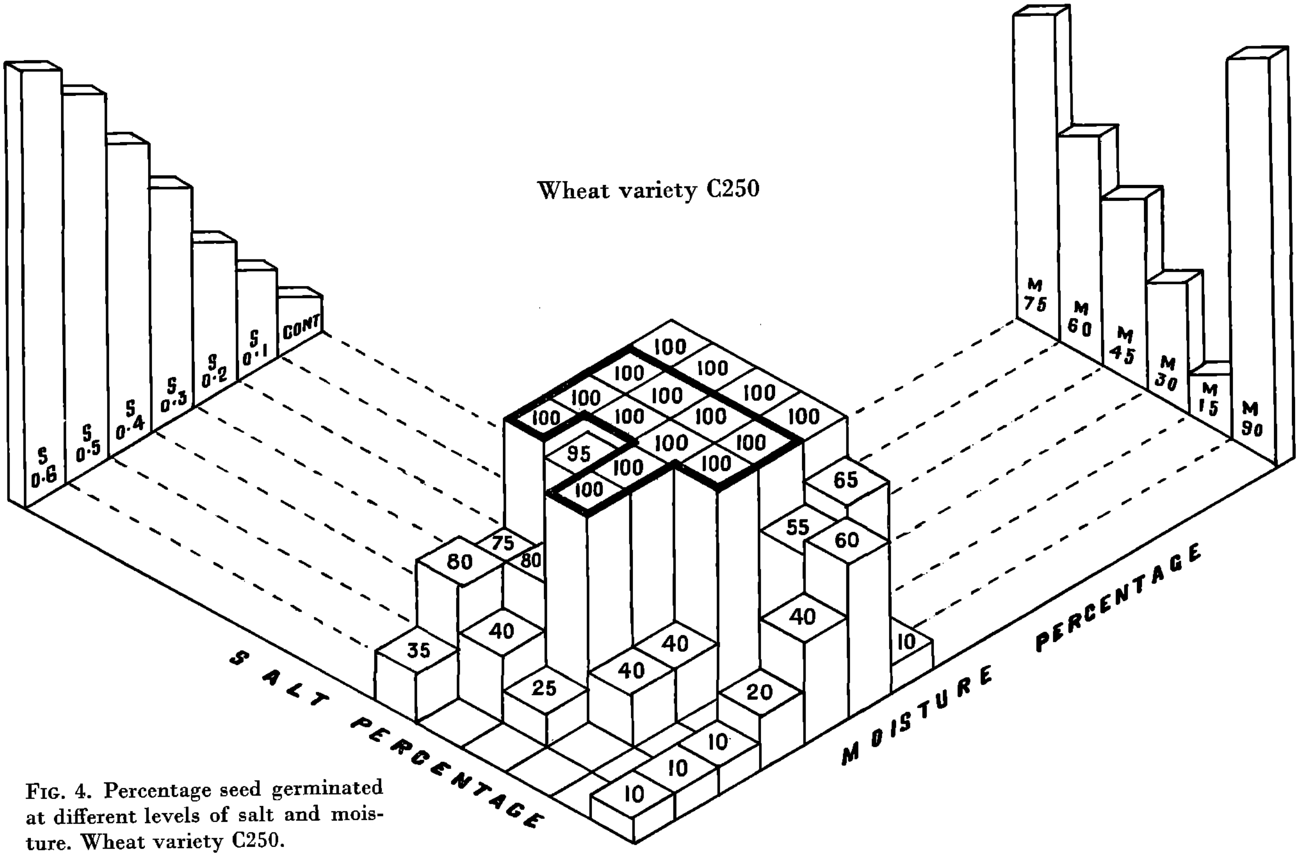

Fig. 4. Percentage seed germinated at different levels of salt and moisture. Wheat variety C250.

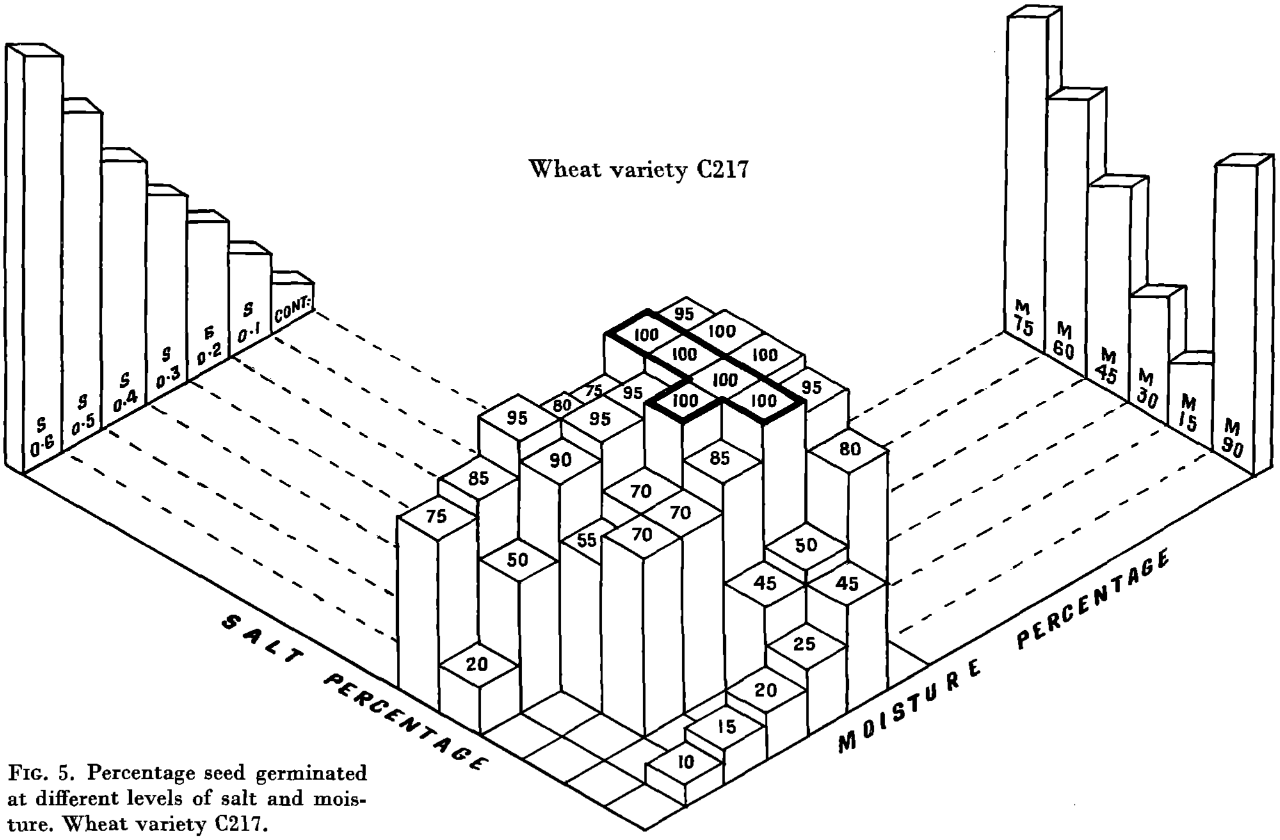

FIG. 5. Percentage seed germinated at different levels of salt and moisture. Wheat variety C217.

quite satisfactorily with up to 0.2 per cent NaCl, beyond which germination decreases progressively with the increase in the salt concentration, until at 0.5 and 0.6 per cent NaCl there is no germination. When the moisture is raised to 45 per cent of the water-holding capacity, good germination is possible with up to 0.4 per cent NaCl content of the soil; this is true of all the varieties. In the case of C250 the germination was even 100 per cent at this concentration. By holding the moisture level at 60 per cent of the water-holding capacity, 100 per cent germination can be obtained in the case of C591 with 0.4 per cent salt concentration. Excepting C250, all the other varieties attained about 50 per cent germination level with 0.5 per cent NaCl. Varieties C591, C217 and C228 germinated from 50 to 60 per cent even when the NaCl concentration was 0.6 per cent, provided the moisture level was maintained at 75 per cent of the water-holding capacity.

From the above, it is clear that germination is dependent upon the soil moisture, particularly under saline conditions. The concentration of the soil solution is related to soil moisture. The salt tolerance of the plant varieties mentioned changes with the increase or decrease of the soil moisture. Generally, the tolerance increases with the increase in the soil moisture, for obvious reasons.

In order to access the relative salt tolerance of these varieties, the number of their seeds which germinate at 45 per cent moisture of the water-holding capacity—which represents the field capacity—may be compared. A study of figs. 1–5 will indicate that C250 is the most salt-tolerant of the wheat varieties, and C217 is the least salt-tolerant. Varieties C591 and C228 come next to C250 and have virtually identical tolerance, C518 occupying the third position.

Maize

The data for three varieties of maize, Hybrid 7, Hybrid 8 and Hybrid 59, are presented in Table 2. At a moisture level of 15 per cent of the water-holding capacity, germination is quite unsatisfactory, even with low levels of salt concentration. In comparison to wheat, maize seems to be more sensitive to a low level of soil moisture. At a moisture level of 30 per cent of the water-holding capacity Hybrid 7 has shown tolerance of salt of up to 0.2 per cent concentration. Beyond this salt percentage, there is no germination. With up to 0.2 per cent NaCl concentration the germination is 100 per cent for all the varieties at 45 per cent moisture of the water-holding capacity. Above this limit germination is affected adversely in case of Hybrid 7 and Hybrid 8. Varieties Hybrid 7 and Hybrid 59 show excellent salt tolerance even at 0.4 per cent salt concentration. Beyond this limit Hybrid 8 is better than the other two varieties. At a moisture level of 60 per cent of the water-holding capacity all the varieties germinated quite satisfactorily up to 0.4 per cent salt concentration. At 0.5 per cent salt concentration the percentage of germination is 80 for all the varieties. The data show that the germination percentage at higher salt levels increases with the increase in soil moisture up to 60 per cent of the water-holding capacity. At a moisture level of 75 per cent of the water-holding capacity, germination is 100 per cent up to 0.3 per cent NaCl concentration: beyond this level germination is poorer than when moisture represents 60 per cent of the water-holding capacity.

It will be clear from the above that salt tolerance depends upon the soil moisture present in the seed-bed. At field capacity, all the varieties show good salt tolerance.

Barley

The data for two varieties (T5 and C141) tested are given in Table 3. At a moisture level of 15 per cent of the water-holding capacity both the varieties failed to germinate. The rest of the data clearly show that the variety T5 is more salt tolerant than variety C141. The data also show that soil moisture beyond the field capacity (i.e. 45 per cent of the water-holding capacity) does not affect the germination with up to 0.4 per cent salt concentration. If the salt concentration rises to 0.5 per cent, then excellent germination is possible with moisture at 60 per cent of the water-holding capacity.

Gram

Two varieties, Pb. 7 and C12/34, were used; the results are given in Table 4. Gram seems to be very susceptible to salts. There was no germination when moisture was at 15 per cent of the water-holding capacity. At a moisture level of 30 per cent of the water-holding capacity, the deleterious effects of the salts on emergence is clear. With the increase in the soil moisture the percentage germination also increases, but generally these germinations are poor. Good germination is only possible with moisture amounting to 75 per cent of the water-holding capacity and with up to 0.3 per cent salt concentration. Variety C12/34 is more salt tolerant than variety Pb. 7.

Rice

The data for the six varieties of rice, Mushkan 7, Mushkan 41, Jhona 349, Malhar 346, Basmati 370, Palman 246 and Sathra 278 are given in Table 5. This table shows that at the first two water-levels either there is no germination or it is very poor. At a moisture level equivalent to 45 per cent of the water-holding capacity the germination is poor beyond 0.2 per cent salt concentration. At a moisture level of 60 per cent of the water-holding capacity, Basmati 370, followed by Mushkan 7, showed better salt tolerance than the other varieties. However, at a moisture level of 75 per cent of the water-holding capacity, this order is reversed and Mushkan 7 shows excellent salt tolerance. At a moisture level of 90 per cent of water-holding capacity, the emergence figure for Basmati 370, Palman 246 and Sathra 278 is 100 per cent with up to 0.4 per cent salt concentration. If the soil moisture is taken into consideration, then we can say that Mushkan 7, Basmati 370, Palman 246 and Sathra 278 are varieties exhibiting good salt tolerance.

Cotton

Nine varieties of cotton, L.S.S., 4F, 119S, 124F, 199F, 39M, 238F, 268F, and 289F/43 were tested. The results are given in Table 6. Cotton does not germinate at all at a moisture level of 15 per cent of the water-holding capacity. This may be due to the hard shell of the seed. At a moisture level of 30 per cent of the water-holding capacity cotton exhibits extreme intolerance of salt concentrations. Germination suffers even at 0.1 per cent NaCl concentration. At a moisture level of 45 per cent of the water-holding capacity only two varieties, L.S.S. and 199F, attained the level of 100 per cent germination at 0.2 per cent NaCl concentration. However, the varieties 4F, 124F and 199F show greater tolerance at 0.3 per cent salt level. The same varieties germinate to 40 per cent when the salt concentration is raised to 0.4 per cent, beyond which no variety germinates. At a moisture level of 60 per cent of the water-holding capacity the emergence percentage increased to 100 per cent in all but two cases with a 0.2 per cent salt concentration. At the 0.3 per cent level of salt, varieties 119S, 124F and 238F exhibited up to 70 per cent germination, while in the case of variety 199F the emergence is 80 per cent. With a 0.4 per cent salt concentration varieties L.S.S., 124F, 238F and 289F/43 germinate to 40 per cent, while germination in the case of variety 4F is 50 per cent. At 0.5 per cent concentration, the emergence for the varieties L.S.S., 4F and 289F/43 is 30 per cent. At a moisture level of 75 per cent of the water-holding capacity the variety 238F germinates to 100 per cent with a salt concentration of 0.3 per cent. With this highest moisture level variety 238F shows the greatest tolerance of salts.

Generally, the salt tolerance increases with the increase in the moisture level. Varietal salt tolerances change with the change in the soil moisture level.

Similar studies were also made using a sandy loam soil. The most important effect of the mechanical composition of the soil is that at any given salinity and moisture level the emergence percentage of seed is lower in a sandy loam than in a loam. This is because the moisture levels in these soils were adjusted according to their water-holding capacities; moreover, the osmotic pressure of the soil solution will always be higher in a lighter soil than in a heavier soil, and this will affect the emergence of seeds.

It is quite possible that a crop variety which is salt-resistant at the germination stage may not be salt-tolerant at the later stages of growth. However, it may be pointed out that salt tolerance at the germination stage is the most important quality.

RÉSUMÉ

La tolérance au sel de diverses plantes de culture au stade de la germination (A. Wahhab)

L'auteur décrit certaines expériences visant à déterminer la tolérance des graines au sel, en fonction de la salinité et du degré d'humidité du sol. On a calculé les pourcentages de germination de diverses semences – blé, maïs, orge, pois chiche, riz et coton – dans des sols argileux et sableux présentant divers degrés de salinité et d'humidité. Les résultats montrent que la tolérance au sel augmente avec le degré d'humidité.

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ADAPTATION OF RUMINANT ANIMALS TO VARIATION OF SALT INTAKE

by

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In considering the physiological effects of salinity of water, a primary consideration would appear to be the maximum NaCl concentration tolerated. As well as other factors, this is a function of the concentrating ability of the kidney and the water content of food eaten. The content of ions with particular physiological activity, such as Mg^{++}, SO_4^{--}, and fluoride is also important. In parts of Australia cattle are known to thrive on waters containing around 15,000 ppm. total solids (equivalent to approximately 250 mM/l. NaCl) and sheep on water containing 19,000 ppm. (equivalent to 320 mM NaCl/l.). However, from experience on the cattle droving routes in the Northern Territory of Australia it is clear that tolerance is also, to a considerable extent, a function of adaptation.

In view of the subject of this arid zone symposium, it may seem paradoxical that we wish to deal mainly with experiments concerning Na^+ depletion. We hope this element of paradox will be resolved by the data presented.

At the Department of Physiology, University of Melbourne, we have been studying the organization of body fluid control and secretory physiology in the sheep. A sheep secretes 4–8 l. of hypertonic alkaline saliva each day. This fluid buffers the acids produced in the rumen by microbial fermentation of grass, chaff, etc., which the animal eats. If a permanent unilateral parotid fistula is made by the method of Pavlov-Glinski or Wright, the sheep loses 2–4 l. each day of this saliva. The Na^+ concentration is normally 180 meq./l., K^+ 5–10 meq./l. (Na^+/K^+ ratio = 18–36). The principal anion is HCO_3^- (100–140 meq./l.). The Cl^- concentration is 10–15 meq./l. and HPO_4^{--} 20–50 meq./l.

The secretion of saliva in the sheep is continuous, although the rate undergoes wide variations caused by afferent stimuli from the mouth and rumen as well as psychic influences. A sheep with a parotid fistula remains in good condition indefinitely if given an ordinary diet and enough $NaHCO_3$ each day (about 25–50 gm.) to replace that lost from the fistula. The digestive processes proceed normally even though the secretion of one of the parotid glands does not enter the alimentary canal. (See Plate I.) If the daily Na^+ supplement is withdrawn, the animal becomes depleted of 400–900 meq. of Na^+ over a period of 4–10 days. Some striking physiological changes occur. The Na^+ concentration of the saliva decreases and the K^+ concentration rises reciprocally, so that eventually the Na^+/K^+ ratio may have changed from a normal of 180/10 = 18 to as low as 20/160 = 0.1. The saliva, however, retains its alkalinity and osmotic pressure, the essential change being the reciprocal alteration of Na^+ and K^+ concentration. At the same time, Na^+ concentration falls rapidly in the urine so that by 48 hours after Na^+ depletion commences there is virtually complete conservation. The urinary K^+ concentration also falls precipitately so that, in effect, the large urinary K^+ excretion characteristic of an herbivore is transferred from the urine to the saliva. There is also a decrease in saliva volume/day. These changes are well shown in Table 1 for an individual sheep, P.F.1—a merino. It shows the cumulative Na^+ balance over a 14-day episode of Na^+ depletion. The extent of change of the parotid salivary composition resulted in a great reduction of the daily Na^+ loss. The animal ate all its food each day and digested it normally so that, as the table shows, it was in Na^+ equilibrium after the 7th–8th day of depletion with a residual Na^+ deficiency of 900 meq. Replacement of the animal's daily Na^+ supplement repaired its Na^+ deficiency, and caused the salivary composition to return to normal.

Table 2 shows the effect of Na^+ deficiency upon the external balance of Na^+, K^+ and Cl^-. Withdrawal of the $NaHCO_3$ supplement caused a negative Na^+ balance of 970 meq. which was corrected when the supplement was replaced. Conversely, during Na^+ depletion there was a positive K^+ balance of 257 meq. and during Na^+ replacement the K^+ balance became negative again. During Na^+ depletion, the Cl^- balance became negative also (—241 meq.) as a result of renal activity regulating the animal's acid-base balance in the face of $NaHCO_3$ loss from the fistula. Upon Na^+ replacement, an approxi-

TABLE 1

Period	Na^+ intake	Na^+ output	Daily Na^+ balance	Cumulative Na^+ balance for period	Saliva		
					Vol.	Na^+	K^+
	meq.	meq.	meq.	meq.	l.	meq.	meq.
Control period 5 days	3 448	3 392	+ 11	+ 56	3.12	178	21
Na^+ withdrawal							
1st day	87	415	— 328	— 328	2.65	154	35
2nd day	87	325	— 238	— 566	2.28	140	56
3rd day	87	218	— 131	— 697	2.02	105	86
4th day	87	113	— 26	— 723	1.47	73	119
5th day	87	150	— 63	— 786	1.89	76	113
6th day	87	161	— 74	— 860	2.00	79	120
7th day	87	119	— 32	— 892	1.73	67	130
8th day	87	134	— 47	— 939	1.90	68	126
9th day	87	98	— 11	— 950	1.72	55	125
10th day	87	77	+ 10	— 940	1.42	52	130
11th day	87	146	— 59	— 999	2.56	56	130
12th day	87	74	+ 13	— 986	1.31	54	134
13th day	87	70	+ 17	— 969	1.47	46	140
14th day	87	85	+ 2	— 967	1.60	50	136
Na^+ replacement							
1st day	689	261	+ 428	— 539	1.64	122	62
2nd day	689	407	+ 282	— 257	1.70	164	33
3rd day	689	532	+ 157	— 100	1.80	185	19
4th day	689	648	+ 41	— 59	2.21	189	14
5th day	689	599	+ 90	+ 31	1.47	203	11

TABLE 2

Period	Na^+ meq.			K^+ meq.			Cl^- meq.		
	Total intake	Total output	Balance	Total intake	Total output	Balance	Total intake	Total output	Balance
Control period 5 days	3 448	3 392	+ 56	2 013	2 104	— 91	878	917	— 39
Withdrawal period 14 days	1 223	2 193	— 970	5 635	5 378	+ 257	2 275	2 516	— 241
Post-withdrawal period A, 7 days	4 232	3 570	+ 652	2 698	3 209	— 511	1 103	878	+ 225
Post-withdrawal period B, 12 days	8 274	7 988	+ 286	4 968	4 998	— 30	1 890	1 850	+ 40

mately equivalent amount of Cl^- was retained. During Na^+ depletion the sheep lost approximately 2.2 kg. in weight: this was regained upon replacement of the $NaHCO_3$ supplement.

The efficacy of this salivary adaptation is well shown in sheep P.F.7—a Suffolk (fig. 1). In fig. 1, the parotid salivary Na^+/K^+ ratio of the sheep is shown (X- - -X) and the blocks underneath refer to the Na^+ intake given to this sheep. The animal was Na^+ depleted for 70 days, and withdrawal of the daily Na^+ supplement caused the salivary Na^+/K^+ to decrease from 18 to 0.2–0.5. On the 8th and 12th day after withdrawal, a small dose of Na^+ was given and the salivary Na^+/K^+ reflected this change of Na^+ balance. From the 27th to the 72nd day, the animal was provided with a Na^+ supplement of 100 meq./day to counter fistula loss and the salivary Na^+/K^+ rose to approximately 1.0 and fluctuated around this figure, reflecting a new equilibrium with a smaller residual Na deficiency.

In the light of this finding, we also made a unilateral parotid fistula in a cow and a goat. In fig. 1 the results are compared with the sheep, and it is shown that the cow was able also to live in good condition for months with its digestive fluids changed considerably towards being a K^+ secretion. The goat showed the same effect, but its fistula stenosed after 4–6 weeks. Though the cow probably lost 20–40 l./day of saliva, because of the lowered salivary Na^+/K^+, the Na^+ obtained in its food, and the small amount of Na^+ in the artesian bore water it drank, it was able to live for months with a fluctuating residual Na^+ deficiency.

In summary, the composition of a ruminant's parotid

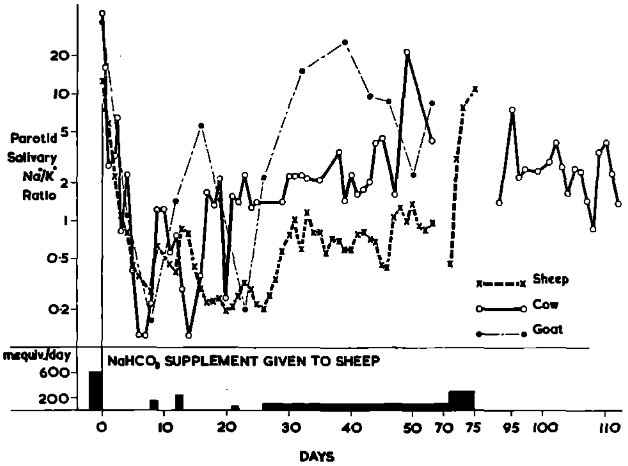

FIG. 1. Salivary secretion in sheep and cattle.

saliva varies with Na$^+$ balance over a quantitative range Na$^+$/K$^+$ 30–0.1—a larger change than any hitherto recorded for a secretory tissue.

The following considerations suggest that this remarkable physiological finding is relevant to arid ecology. The volume of parotid saliva secreted by a sheep is determined by the physical composition of the food it eats. For example, P.F.1 secreted 3.2 l./day when eating mainly oaten chaff (0.8 kg./day, water content 10 per cent) whereas it secreted 1.5 l./day when eating 1 kg. chopped green lucerne (water content 60–70 per cent). It secreted 2.68 l./day when eating a mixture of equal parts of the two. Further, when an animal has been eating fresh lucerne only for some days and chaff is provided for the first time, the increase of salivary rate is apparent within 12 hours and is associated with an evident increase of rumination. The dynamics of digestion in the ruminant involve a considerable volume of fluid being present in the rumen at any one time. In sheep which have been killed in the laboratory or the field, we have found 2–6 l. of fluid containing as much as 300–700 meq. of Na$^+$ in the rumen. In the instance of a Na$^+$ depleted sheep being killed, it has been found that the rumen fluid composition reflected the salivary change.

The possibility emerges, therefore, that ecological conditions involving slow or rapid change of a ruminant's food supply from lush green to very dry would involve the secretion of considerably more saliva to ensure efficient digestion in the rumen fluid pool. The withdrawal of 300–500 meq. of Na$^+$ from the circulating plasma and extracellular fluid would cause circulatory and general physical deterioration. Thus the operation of a mechanism which to a considerable extent changed the digestive fluid cycle to a K$^+$ secretion would be of considerable survival advantage, since this cation is abundantly available in plant food. The likelihood that such a mechanism might operate in some climatic conditions is supported by analyses of grasses, and trees which are commonly cut for drought feeding, in the centre of Australia—an enormous area with less than 20 in./year rainfall. Table 3 shows that, with the exception of the lucerne grown on a pasture watered by bore water containing 1,000 parts per million of total solids, both grasses and trees have an extremely low Na$^+$ content—often below 5 meq. Na$^+$/kg. dry weight. Thus if an animal had need of an extra 2–3 l. of saliva for effective digestion, it would take some weeks to repair the extracellular Na$^+$ deficit from the Na$^+$ in the food consumed. In these conditions, the presence of some Na$^+$ in drinking water could be physiologically advantageous.

TABLE 3. Analyses of some grasses and stock feeds from Central Australia

Source and specimen	meq./kilogram dry weight		
	Na$^+$	K$^+$	Cl$^-$
Gilruth Plains (Central Queensland)			
Mitchell Grass	3.5	70	31
Blue Grass	3	75	46
Mulga-Mitchell	2.5	68	23
Mulga	2.5	177	85
Rosewood	3	380	103
Wilga	1.4	395	150
Gidgyea	2.2	195	230
Leopard-wood	4.8	260	135
Supplejack	1.4	220	37
Argadargarda (Central Northern Territory)			
Windgrass	19	95	68
Mulga	11	200	92
Gidgyea	7	235	218
Supplejack	16	270	58
Whitewood	9	350	126
Gidgyea (ground toxic)	1.5	265	150
Lucerne (pasture (1)	62	565	295
irrigated with (2)	67	570	280
bore water—N$^+$ content = 5 meq./l.)			
Victoria (Temperate coastal)			
Oaten chaff	136	233	172
(15 specimens)	(20–350)	(170–315)	(80–265)
Lucerne chaff	80	487	184
(14 specimens)	(20–200)	(360–650)	(150–210)

Other questions arise which highlight the need for further investigation of fluid control in the ruminant. In starvation, the completion of digestion of the food remaining in the rumen would involve, presumably, reduction of the rumen pool of saliva. Would the absorption of this saliva into the plasma and extracellular fluid disturb the steady state and cause part or the whole of this influx of Na$^+$ to be excreted by the kidney? If so, when next the animal fed, would it in the course of initiating digestion deplete its circulation of Na$^+$ and stimulate the mechanism, causing the salivary Na$^+$/K$^+$

ratio to decrease? The answer to these questions might be important in arid and drought conditions and raise the question of provision of some Na^+ if feeding were episodic.

An extensive series of experiments has shown that the major cause of decreased salivary Na^+/K^+ ratio during Na^+ deficiency is the increase of electrolyte-active steroid secretion of the adrenal gland. The mechanism does not occur in an adrenally insufficient animal. With the aim of trying to identify stimulus causing increased secretion by the adrenal gland in Na^+ deficiency, the adrenal gland has been transplanted by directly anastomosing the renal artery and vein to the carotid artery and jugular vein in the neck. These vessels and the adrenal were then enclosed in a skin loop. This permitted local reduction of the Na^+ concentration and Na^+/K^+ ratio of the adrenal arterial blood in order to determine whether this reproduced the effect of Na^+ deficiency. It was found that local change of the Na^+ and K^+ concentration of adrenal arterial blood was not, of itself, a sufficient cause of the changes of electrolyte-active steroid secretion which occur during alterations of Na^+ balance. These local changes did, however, have some effect and appear to be a contributory cause of this adrenal secretion. Further experiments have given an indication that another factor stimulating the adrenal secretion might be a humoral stimulus from the diencephalon. If evidence substantiating this is forthcoming, the question emerges whether the remarkable selective appetite for Na^+ shown by Na^+-deficient sheep is the cortical behaviour determining projection of a diencephalic centre controlling the secretion of a trophic hormone. It has been found that a Na^+-deficient sheep will lick much more off a block of rock salt than a sheep in normal balance. If a sheep with a parotid fistula was presented with the choice of a variety of solutions (e.g. 420 meq./l. NaCl, 420 meq./l. $NaHCO_3$, 140 meq./l. KCl, and H_2O), it usually drank little except water when in normal Na^+ balance. However, Drs. McDonald and Raschke found that if its Na^+ supplement was withdrawn it first drank 0.5–2.0 l./day of the NaCl, but after some days changed to drinking the same volume of the $NaHCO_3$ solution—a choice more appropriate in the face of its predominantly $NaHCO_3$ loss from the fistula. We found that this appetite was related to need in that if the concentration of the electrolyte-containing fluid was altered from one-quarter to twice the concentration of the arbitrary standard cited above, the volume drunk by the animal changed in the direction of maintaining the Na^+ intake constant. Whereas usually the Na^+-containing solutions were available continously, it was found that the animals drank the same adequate amount if they were available for 10–15 min. only each day. This permitted precise analysis of the animal's sampling behaviour in this context, and also when the experimental situation was modified by concurrent water depletion. It was clearly shown that the increased appetite was associated with an increased number of episodes of smelling, tasting, and drinking the Na^+-containing solutions. Experiments are proceeding in which the chemical composition of the blood in the animal's head has been significantly modified by infusion of Na^+-containing fluids into the common carotid artery during the period of choice with the object of identifying the mechanism determining this behaviour.

Thus the experiments show that sheep will drink water containing considerable amounts of Na^+ by preference if they have need of Na^+. On the other hand "aberrations" of behaviour have been observed with some animals in that having once had an episode of Na^+ deficiency and commenced drinking hypertonic Na^+ solutions, the animal thereafter drinks large volumes of them daily during months, although adequate Na^+ is given to it by other means and there is no body deficit.

To summarize, the results suggest that some of the basic regulatory mechanisms common to all higher species have been refined considerably in the course of the evolution of ruminant animals. The refinements could carry survival advantage because they permit wide variation

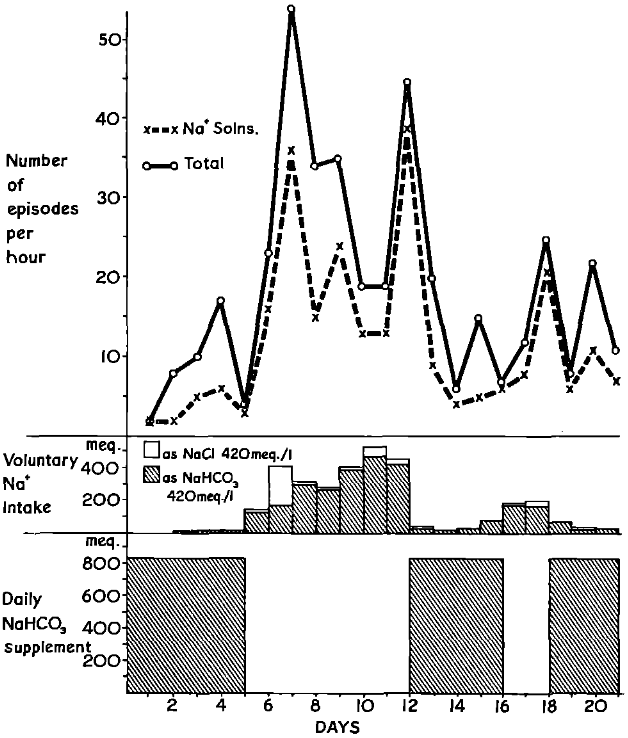

FIG. 2. Selective appetite of a Na^+-deficient sheep for Na^+-containing solutions. The upper section of the graph shows the number of episodes of tasting, smelling or drinking solutions containing NaCl or $NaHCO_3$ during a test period of one hour each day. The middle section shows the amount of NaCl and $NaHCO_3$ drunk during this period. The lower section shows the days on which a $NaHCO_3$ supplement of 800 meq. was given. Na^+ deficiency produced by withholding the supplement caused the animal to drink Na^+-containing solutions (mainly $NaHCO_3$) and to show an increased interest in the solutions.

of salt balance without deterioration of digestive and other functions. Na^+ deficiency initiates a series of integrated mechanisms modifying behaviour, stimulating endocrine secretions which alter the composition of the fluid in the digestive cycle, and causing ionic conservation by the kidney. The experimental procedures which have revealed these homeostatic capacities cause large changes of external Na^+ balance, but reasons are advanced for suggesting that similar effects could occur under some arid ecological conditions as a result of digestive demands causing a redistribution of fluid between the rumen and the extracellular fluid compartment. Under these conditions the presence of some Na^+ in drinking water may be temporarily beneficial. Further study of grazing habits of ruminants might bring to the fore the question whether there is seasonal variation in the choice of available plant food because the particular mineral content may determine palatability in the face of seasonal fluctuations in the animal's requirements for normal mineral balance.

RÉSUMÉ

Adaptation des ruminants aux variations de la quantité de sel absorbée (D. A. Denton, J. R. Goding, I. R. McDonald, R. Sabine et R. D. Wright)

Les recherches expérimentales effectuées par ce groupe de chercheurs semblent montrer que, chez les ruminants, certains des mécanismes régulateurs fondamentaux qui sont communs à toutes les espèces supérieures se sont beaucoup perfectionnés au cours de leur évolution. Ces perfectionnements ont pu favoriser la survivance des ruminants, qui peuvent, grâce à eux, supporter de grandes variations dans l'équilibre des sels sans que leurs fonctions, digestives ou autres, en souffrent.

Chez le mouton, la digestion est conditionnée par la sécrétion quotidienne de 4 à 8 litres de solution alcaline de sodium; chez les bovins, cette quantité est de 10 à 15 fois plus grande. La salive neutralise les acides que produit la fermentation bactérienne des aliments dans le rumen. On a constaté que, si un ruminant manque de Na^+, la solution de Na^+ dans ses sécrétions gastriques peut se transformer en une solution où domine K^+, que l'animal trouve facilement dans l'herbe qu'il mange. On a constaté également qu'il faut à un ruminant deux fois plus de salive pour digérer des aliments très secs que pour digérer des plantes succulentes. Si son alimentation se transforme de la sorte, brusquement ou lentement, il peut donc produire le supplément nécessaire de salive sans avoir recours aux réserves de Na^+ qui existent dans sa circulation sanguine. Il y a là, dans certaines conditions, une importante faculté d'adaptation qui épargne à l'animal des troubles de tension sanguine et d'état général. La présence constatée d'une très faible teneur en Na^+ dans les herbes, et dans quelques arbres que l'on coupe ordinairement pour alimenter le bétail en période de sécheresse, à l'intérieur de l'Australie, confirme que ce mécanisme physiologique pourrait avoir une grande importance.

En cas de déficience en Na^+, le rein conserve entièrement Na^+; l'étude du comportement d'animaux déficients en Na^+ montre également que les transformations du suc gastrique par le fait d'hormones s'accompagnent de transformations dans le fonctionnement du cerveau, ainsi qu'en témoigne une appétence remarquable pour Na^+.

Ces considérations physiologiques incitent à se demander si la présence d'une faible quantité de NaCl dans l'eau dont s'abreuvent les animaux ne pourrait pas leur être salutaire dans certaines conditions.

DISCUSSION

D. S. Jenkins. Desalted water produced through such processes as distillation is essentially free of all minerals. For human or animal consumption of such water it is necessary that some minerals be restored to the distillate. Most studies and criteria regarding human and animal tolerance of minerals in water, including the Public Health Standards, relate to *maximum* tolerances for various minerals. In situations where the mineral content of the original water is suitable, a portion can be blended back with the distillate. In fact this may even reduce the total cost of the product significantly. But in situations where the necessary minerals must be added in the form of concentrates, their cost may be significant.

Could Dr. Denton suggest any criteria or literature that would be helpful as a guide in determining the *minimum* amounts of minerals needed to sustain mineral balance and health in humans and animals?

D. Denton. The question is difficult to answer. In the case of humans living and working in hot arid areas, the daily loss of Na^+ and Cl^- in sweat may be equivalent to the amount of these ions in 2–3 l. of blood plasma or more. It is important for health that this loss be replaced, and hence it would be advantageous if the drinking water contained NaCl. If consumers become conditioned to it, water containing 2,000–3,000 ppm. (*circa* 30–50 meq./l. NaCl) can be used for domestic consumption. However, even this Na^+ content will not replace loss if the climate causes considerable sweating, and addition of NaCl to food would be essential. The addition of some of the original saline water to the distillate would be practicable, provided the content of ions like Mg^{++}, SO_4^{--}, NO_5 and fluoride was not above 200, 400–500, 120, and 1 ppm. respectively in the final product.[1] An objection to having water of such high Na^+ content would arise in the case of hospitals in these areas, and of patients on low Na^+ diets because of heart disease, hypertension or some types of kidney disease. This presumably could be met as a special instance. With regard to animals, I think the question requires a field investigation of the fluid physiology of animals under the types of climatic conditions which may arise. We have suggested in the paper communicated that a considerable Na^+ content in water may be an advantage to animals under defined conditions.

C. **Gomella**. M. Denton peut-il donner quelques renseignements sur l'effet des sels de calcium et de magnésium présents en grande quantité simultanément avec les quantités de chlorure de sodium indiquées dans la communication?

D. **Denton**. I regret I have no information on this. I think Pearce has done some work along these lines. If both Ca^{++} and Mg^{++} were absorbed in amounts adequate to raise blood concentration, their physiological actions would in some respects tend to cancel out. Pech and Metler investigated the antagonistic effects of these two ions at the Rockefeller Institute in about 1924.

R. **Ambroggi**. Avez-vous exécuté en laboratoire l'expérience qui consisterait à augmenter la dose de NaCl contenue dans l'eau d'abreuvement des moutons?

D. **Denton**. Yes, we have done a small amount of work along these lines which indicated that the animal gradually adapted to higher concentrations. As far as Australia is concerned the most comprehensive investigations along these lines have been made by Pearce, of the Division of Biochemistry, CSIRO, University of Adelaide, South Australia.

W. **Boby**. Can cattle and sheep be made to tolerate higher concentrations of salinity by gradual conditioning? Does a falling off in condition occur when waters in the upper limits of salinity (19,000 ppm. for sheep) are drunk?

D. **Denton**. Yes. There is evidence from the stock routes of the Northern Territory of Australia that animals which live habitually from a bore of high salinity (10,000 ppm.) can thrive, whereas cattle meeting such concentrations suddenly in the course of droving will refuse the water. The figure we quoted as the upper limit in sheep, 19,000 ppm. was suitable for the animals under the conditions where there was green food (with a high water content). As far as we know, in the case of animals eating dry food, the upper limit for sheep is in the region of 10,000–12,000 ppm.

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III

USE OF BRACKISH WATER IN IRRIGATION AND SALINE SOILS

IRRIGATION À L'EAU SAUMÂTRE ET SOLS SALÉS

PRINCIPLES OF THE THEORY AND PRACTICE OF RECLAMATION AND UTILIZATION OF SALINE SOILS IN THE ARID ZONES

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Saline soils are an essential element of the arid zone landscapes. Although maritime solonchak soils occur in other natural zones of dry land, soil salinization in marine lowlands nevertheless reaches its maximum in the arid zones.

It is necessary to distinguish the following cycles of salt accumulation in the geography and geochemistry of the processes pertaining to the formation of saline soils.

Continental cycles, connected with the movement, redistribution and accumulation of carbonic, sulphuric and chlorous salts in inland regions that have no run-off.

Depending on the origin of the salts accumulated in soils and waters (i.e. whether they are the products of weathering of igneous rocks or connected with the redistribution of salts formerly accumulated in the masses of sedimentary salt-bearing rocks) one distinguishes Primary salt accumulation cycles (e.g., the Small Caucasus, Manchuria, Mongolia), and Secondary salt accumulation cycles (e.g., Ferghana, Tadjikistan, Sinkiang or Iran).

Marine cycles, connected with the accumulation of marine salts, mainly sodium chlorides, on the coastal plains of dry land and along the shores of shallow bays.

Delta cycles, widely distributed in nature and of great importance for mankind, in so far as areas of river deltas have been extensively used for irrigation since ancient times (the deltas of the rivers Amu-Darya, Tigris and Euphrates, Hwang-ho, and Nile). These cycles are characterized by a complicated combination of movement processes, and by the accumulation of salts carried from the continent by rivers and delta-valley ground streams on the one hand, and that accumulation of salts carried in from the sea at different times, on the other.

Artesian cycles, connected with the evaporation of deep underground waters and their thinning out on the surface through tectonic fractures and destroyed structures (mud volcanoes of the Caspian region) or in vast deep continental depressions (Kattara in North Africa, the Ust-Urt depressions in Asia).

Anthropogenic cycles, resulting from errors in the economic activities of man, or from a lack of knowledge of the laws of salt accumulation (e.g. salinization of irrigated soils as a result of a rise in the ground-water level; salinization of meadows through over-pasturing; irrigation by mineralized waters; flooding by waters from mining shafts, by petroleum and other industrial waters).

Salt accumulation processes are connected with definite types of relief, with certain geomorphological and hydrogeological conditions. Salt accumulation in different cycles is linked geomorphologically to lowlands or their component parts (flood-plains, deltas, troughs, low river terraces (benches), lake or coastal terraces). From the point of view of hydrogeology the processes are related to regions with high water tables (within the limits of the capillary and film-capillary rise of solutions). Hydrologically, salt accumulation phenomena occur particularly in regions where run-off is slight or virtually absent, and where the ground-water balance is not regulated by run-off, but by evaporation and transpiration. In relation to soils, salt accumulation is connected with conditions of the contemporary or the ancient accumulative soil formation process.

A common and direct contributing factor in the formation of contemporary saline soils is ground-water evaporation and transpiration in conditions in which run-off is reduced or absent. The intensity of ground-water evaporation and the process of salt accumulation in ground-waters and in the soils augment when the ground-water level approaches the surface and, beginning at depth of 2–3 m. or less, the salt accumulation processes, in arid climate conditions, reach maximum values (fig. 1).

Total evaporation in arid zones reaches 1,500 to 3,000 mm. per year, thus exceeding by far the sum of atmospheric precipitation, which may not occur at all in typical deserts in a number of years.

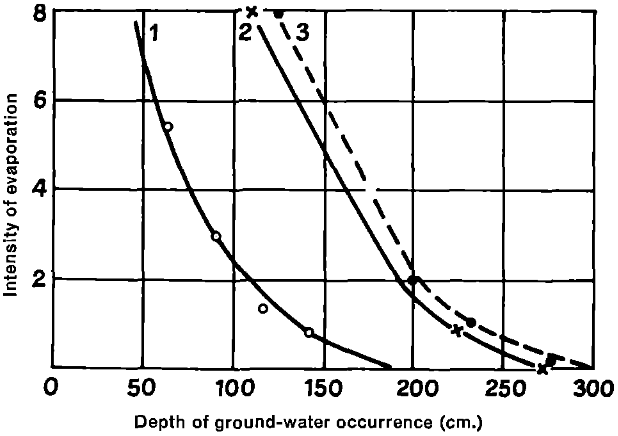

FIG. 1. Dependence of evaporation intensity of ground-water on the depth. 1. Baraba; 2. Bukhara; 3. Golodnaya steppe.

The process of contemporary salt accumulation may also depend to a slight, or even a decisive extent, on evaporation: (a) of superficial deluvial-proluvial waters (in dry deltas during salt redistribution from ancient sedimentary rock masses); (b) of sea-waters, particularly after the flooding of dry land by high tides or hurricanes; (c) of underground waters (e.g. waters from mud volcanoes in the Transcaucasian region and in Turkmenia); (d) of irrigation waters if their mineralization exceeds 1–2 gm./l.

Since natural waters, particularly the mineralized ones, contain a complicated complex of dissolved compounds, the process of evaporation and transpiration brings about the automineralization of ground-waters, the accumulation of weakly soluble components (clay, silica, sesquioxides, calcium, carbonate, gypsum in the solid phase) which form concretions or cemented horizons and crusts in the soil. In soil solutions and ground-waters and in salt crusts soluble salts easily accumulate (carbonates, sulphates, chlorides, nitrates of alkali and partly of alkali-earths in various proportions).

Under arid climate conditions the masses of secondary compounds accumulated in soils, sedimentary rocks and ground-waters have a tendency to long-time conservation even after the end of salt accumulation processes.

After the uplift of the country and the cutting in of the hydrographical network, ground-waters, as a factor of salt accumulation, are excluded, and the processes of salt accumulation break off.

Nevertheless, the predominance of evaporation processes in deserts and steppes and the small amount of atmospheric precipitation lead to the preservation of the accumulated salt masses in soils and subsoil layers. Thus, in important arid zone areas, residual saline soils of various types are formed. Besides, slow processes of desalinization takes place, the speed of which will be the greater the higher the quantity of atmospheric precipitation and the greater the natural drainage of the relief. Natural evaporation (of superficial, ground, underground, lacustrine, and marine waters) is usually the only cause of salt-accumulation and of the formation of gypsum and of calcareous crusts, both today and in past periods.

In order to understand the mechanism of the salt-accumulation processes and to work out measures to combat salinization, it is necessary to take into account the following soil-hydrological constants:

1. Critical mineralization of ground-waters. This term stands for the value of ground-water mineralization above which, in conditions of a hydromorphous soil formation process (in natural conditions or under irrigation and drainage), the capillary-ascending waters from the ground-water table provoke the salinization of the upper soil horizons and the destruction of normal plants.

   For ground-water of the chloride-sulphate type critical mineralization is on the average 2–3 gm./l.; for alkali, soda waters 0.7–1 gm./l.

   If the ground-water mineralization does not exceed this level, there develops, in hydromorphous conditions, a natural or cultivated meadow soil-forming process; highly fertile soils are formed, and the possibility of producing large masses of natural vegetation or very high crops of agricultural plants (cotton plants, lucerne, beetroots, sugar canes, etc.) is guaranteed. If salt concentration in ground-waters exceeds critical mineralization, the process of alkalinization or salinization in hydromorphous conditions begins and the fertility of soils decreases noticeably.

   It is necessary in the course of hydrotechnical reclamation to desalinize the ground-waters of solonchak soils down to a value lower than the critical mineralization.

2. The critical occurrence depth of the level of mineralized ground-waters. Critical occurrence of the level of mineralized ground-waters is defined as the level of the water table expressed in m. or cm., above which salt-bearing solutions will ascend by capillarity from the body of mineralized ground-waters, reach the soil arable horizon, provoke salt accumulation, oppression and ruin of plants.

   The higher the mineralization, the more can ground-waters provoke salinization of soils at a greater depth, and thereby destroy crops. It is possible to state that, generally speaking, if a ground-water mineralization of 10–15 gm./l. is present under arid zone conditions such as obtained in Asia, Africa and Europe, the critical depth will be given by values of about 2–2.5 m.

   From this it follows that, when carrying out hydrotechnical reclamation of saline soils (by drainage, washing, watering, one must maintain the ground-water level on irrigated fields at depths below the critical, i.e. somewhat deeper than an average 2–2.5 m. during the course of the vegetative period. If the mineralization is 1–2 gm./l. in conditions of drainage and irrigation, the ground-waters may occur at depths from 1 m. to 1.5 m. and not provoke salinization of soil.

The critical occurrence depth of the level of saline ground-waters depends also upon the rate of evaporation, in a given area. As a rough approximation, and on the basis of empirical data, one may assume it to be proportional to the average annual temperature; $y = 170 + 8\,t^\circ \pm 15$, where y is the critical depth in cm., and t° the average annual temperature of the area.

3. Levels of the physiological toxicity of salts. Bicarbonates and alkali carbonates in soils (particularly soda) have the highest degree of toxicity for plants, next come the chlorides and nitrates of alkali; sulphates have the least toxicity. Combinations of salts are always less toxic than accumulations of a pure salt.

   Crop plants come under stress in the presence of carbonate-soda salinization if the content of HCO_3' ions reaches 0.08 per cent in the arable horizon and the *p*H is 8.7–9.0. When the HCO_3' content is 0.1–0.2 per cent and the *p*H is 9.5–10.0, cultivated plants perish.

   In the presence of chloride salinization crop plants begin to suffer marked stress if the chlorine ions in the soil amount to 0.05–0.1 per cent Cl'. On the average, it is thought that at a salt content of 0.4–0.8 per cent most agricultural plants develop in an abnormal way, and yield low crops.

   When the salt content in the arable horizon equals 1.5 per cent and more, most cultivated plants do not develop properly, or they develop in an utterly abnormal way and do not yield any crops.
4. The optimum concentration of salts in soil solutions. The optimum concentration of easily soluble salts in the soil solutions of irrigated soils lies within the limits of 3–5 gm./l. If the concentration is higher than 5–6 gm./l., cultivated plants suffer slight stress; if the concentration is higher than 10–12 gm./l., it leads to marked stress and in the presence of soil solution concentrations of about 20–25 gm./l., the plants perish.
5. Toxic values of exchangeable sodium. Cultivated plants are subjected to slight stress when the quantity of exchangeable sodium is about 10–15 per cent of the absorption capacity of the soil. If the exchangeable sodium content is $\approx$ 20–25 per cent, the stress imposed on the plants is stronger and it is necessary to undertake chemical reclamation in order to reduce the quantity of exchangeable sodium below 10 per cent.
6. Those soils in which the total of salts in the arable and the root horizons is lower than 0.3–0.4 per cent during the entire vegetative period must be considered as non-saline.

   Non-alkaline soils are those in which the reaction is measured by a *p*H of 8.4 and where the total alkalinity is not higher than 0.06 per cent HCO_3'.

CLASSIFICATION OF THE SALINE SOILS IN EURASIA

In establishing a classification of saline soils, it is necessary to combine the principles of the geochemistry of salts and the principles of agrophysiology. Only then is it possible to obtain a notion regarding the origin and forms of saline soils, their natural fertility level and the reclamation work necessary in agriculture.

Salt crusts

In arid countries almost chemically pure salt accumulations (without admixtures of fine earths and skeletons) are often present on the soil surface. The salt content in these is 50–60 per cent of the mass by weight. The thickness of the salt crust may attain 3–5 cm., sometimes 50–100 cm. and even a few metres.

Salt crusts are dense (monolithic) in structure. They have low permeability for solutions; they are not easily penetrated by roots and tilling implements, and in most cases do not possess any natural fertility. They present, nevertheless, an economic interest as sources of raw materials for the chemical industry or for the building materials industry.

One distinguishes among the salt crusts contemporary ones, formed during the present period by evaporation of marine, lacustrine or subsoil ground-waters, and residual ones, the growth process of which does not take place at present, since the marine, lacustrine or subsoil waters are absent.

On the basis of their chemical composition, the following varieties of salt crust may be distinguished:

Calcareous crusts are broadly developed in arid zones of Asia and Africa (*shokh* is their popular name in Uzbekistan; *shetchian* in northern China).

The calcium carbonate content of these crusts is 50–70 per cent. Reserves in mineral nutrition elements and natural fertility are very low. The root-system of plants develops with difficulty. Mechanical treatment and irrigation are strongly hampered because of the great surface hardness. These crusts do not show any physiological toxicity for plants. Development is possible only on an irrigation basis: deep artificial loosening, by means of special machines, and light explosions are necessary.

Calcareous crusts in arid zones are by origin products of the chemical sedimentation of evaporated ground—or lacustrine waters, either in modern or in ancient times.

Gypsum crusts are found in the more torrid and drier parts of arid zones. They are well known in the semi-desert and desert parts of Central Asia, Transcaucasia, and North Africa.

Among gypsum crusts and gypsum horizons we find contemporary ones that accumulate with the evaporation of mineralized ground-waters, and residual gypsum horizons and crusts formed by ground-waters or lacustrine waters in past times.

Gypsum crusts and horizons, which have obtained in Uzbekistan the popular name of *arzyk*, are composed of 60–80 per cent calcium sulphate. Gypsum crusts and horizons, called *gandj* or *gaja*, are well known in Azerbaijan and Georgia; these contain up to 95 per cent calcium sulphate.

Vast areas of residual and contemporary gypsum accumulations in the form of horizons and crusts are found in Uzbekistan, Tadzikistan, on the Ust-Urt, in western China and in Egypt.

The thickness of gypsum crusts and horizons may attain 10–20 cm., and sometimes 50–100 cm. The physiological toxicity of gypsum for plants is not established. The aqueous regime of gypsum-bearing crusts is unfavourable for plants as they are often subject to droughts. The physical properties of gypsum crusts are unfavourable because of the high degree of hardness, the impossibility for roots to penetrate them and the large quantities of crystal-bound water. The reserves in nutritive substances are extremely low. The natural fertility of gypsum crusts is low.

Irrigated gypsum crusts and horizons show strong deformations of a suffusion character. Development of irrigation economies is quite possible, but much work has to be carried out in order to enrich the surface of the gypsum crusts (e.g. addition of fine mineral earths, organic substances and fertilizers).

Salt crusts. In the driest deserts of central Asia, western China, Iran and North Africa the arid climate conditions cause the formation and maintenance of surface and buried salt horizons containing 80–100 per cent of pure salts or of their combinations. The salts are primarily sodium chloride, mirabilite and others.

Contemporary salt crusts of this type sometimes attain a thickness of tens, or even hundreds of centimetres, as they are formed in deep depressions as a result of chemical sedimentation out of highly concentrated lacustrine or subsoil waters with a mineralization of 250–500 gm./l.

Vast residual salt crusts are known in ancient Quaternary, Tertiary, Permian and Devonian sediments; their thickness can be measured in metres.

Owing to the extreme dryness of the climate in the deserts of central Asia, Iran and western China, ancient salt masses, after their outcrop on the surface following tectonic movements, are preserved for a long time and bring about the general salinization of adjoining soils.

Salt crusts of this type are absolutely barren. They cannot be used for agriculture. Nevertheless they are of considerable interest as raw material for the chemical and food industries. However, it would not be rational to include salt crusts of this type in projects for agricultural development and reclamation.

Solonchak soils

Solonchaks are those saline soils that possess the highest quantity or easily soluble toxic salts in the highest soil horizons (0–30 cm.; 0–40 cm.). The total of salts usually exceeds 1–2 per cent, reaching sometimes 10–20–30 per cent. In the main, agricultural plants do not yield crops on solonchaks. In natural conditions vegetation is either absent on solonchaks or is represented by specific succulent halophytes.

According to the chemism of easily soluble salts represented in solonchaks, the latter must be subdivided into soda-solonchak soils, with Na_2CO_3, $NaHCO_3$, $MgCO_3$. The toxicity of these salts is great; this may be explained not only by their direct influence, but also by a high alkalinity, reaching the order of pH 9.5–10.5. The prismoid-block structure is characteristic of these salts.

Owing to very low permeability and peptization of soil colloids, washing and drainage of soda solonchaks are difficult processes. Complementary measures are necessary in order to raise the permeability of soils in the reclamation period: deep tillage, deep ploughing, loosening, temporary shallow drains; also the use of chemicals—gypsum, sulphur, sulphurous iron, acids—to neutralize alkalinity. Most effective are summer leachings, combined with sowing of rice.

Sulphate solonchaks usually contain Na_2SO_4, $MgSO_4$, $CaSO_4$. Among the easily soluble salts, sulphates have the lowest toxicity. The hydrophysical properties of these solonchaks are generally favourable. They do not alkalinize as a result of their natural gypsum content. Leaching and drainage have a light and rapid effect in the period of reclamation and during their application.

Chloride solonchak soils contain NaCl, $MgCl_2$, and sometimes $CaCl_2$. Chlorous salts are highly toxic. The total of salts and the ground-water salinity in solonchak soils with chloride salinization is usually very high. Hydrophysical properties of chloride solonchaks in the washing period depend on whether they are gypsum-bearing or not. If they are gypsum-bearing (and this is generally the case), they are easily reclaimed. Chloride solonchak soils containing no gypsum and with a clayey mechanical composition of parent rock react unsatisfactorily to leaching and drainage, owing to their low permeability, the increase of alkalinity, and the peptization of soil colloids. In such cases, additional measures are necessary to raise the efficiency of leaching (deep loosening, plantage, temporary shallow drains, and sometimes addition of gypsum).

Nitrate solonchak soils, containing $NaNO_3$, KNO_3. In terms of toxicity and reclamation properties nitrate solonchak soils are close to chloride ones.

Chemically pure accumulations of such salts are, naturally, rarely formed in nature. More often combinations of easily soluble salt mixtures, of varying proportions, are found. Therefore, soda sulphate solonchak soils, sulphate-chloride, chloride-sulphate ones, etc., are more widely distributed in nature, depending on the ratio of the main components. Nevertheless, in general, the higher the degree of soil salinization, the more important are the chlorides. On the other hand, the smaller the total amount of salts, the more frequent and the more important are the alkali carbonates and, in particular, soda.

Before reclaiming solonchak soils it is important to evaluate correctly their hydrology and their relation to ground-waters. From this point of view it is necessary to distinguish:

Active solonchaks (contemporary). These are related to ground-waters through a "capillary fringe", or through a filmy-capillary flow of ascending salt solutions. In these solonchak soils the reserve of easily soluble salts, in spite of seasonal variations, grows gradually. The ground-water table in such soils is, at different times of the year, at a depth of 0.5–3 m.

Owing to the usual capillary moistening of solonchak soils, these are wet and therefore often called "wet solonchak soils" (ground-water at 0.5–1 m.), or "moistened solonchak soils" (ground-water at 2–3 m.).

If the mineralization of ground-waters in such solonchak soils does not exceed 5–10 gm./l., leaching may be carried out during reclamation with a moderate quantity of water (5,000–7,000 m.^{3}/ha.), using deep horizontal widely spaced drains (500–1,000 m. between drains; depth of drains 2.5–3 m.). If the ground-water mineralization is high (30–50–100 gm./l.)—and this often occurs in deserts and in coastal regions—the leaching of solonchaks requires very large quantities of water, of the order of 10,000–20,000 m.^{3}/ha, and also a wide network of deep horizontal drains (100–200–400 m. between drains; depth of drains 2.5–3 m.). In such cases it is advisable to do the leaching under crops of irrigated rice, which, it is well known, need great quantities of irrigation waters—20,000–30,000 m.^{3}/ha. during one season (the so-called summer leaching of solonchak soils by rice crops). Leaching on such soils must be repeated during a series of years, with gradually decreasing quantities of irrigation waters.

Residual "dry solonchak soils". These are often found in the arid zones of Africa, Central Asia, and the Transcaucasian region, where ground-waters occur at depths of more than 10 m.; nevertheless, owing to the extreme aridity of the climate, the majority of easily soluble salts in them are concentrated in the upper soil horizons.

In solonchak soils of this type, some soils develop that form a loose clayey salt mass of grains—the so-called "pseudo-sand". Under the influence of wind the pseudo-sand accumulates in salt dunes and salty hillocks. The total of salt in the fluffy saline horizons reaches 20–25 per cent, and in the salt dunes even 50 per cent.

When developing and reclaiming such solonchak soils, it is advisable to remove mechanically the main part of the fluffy salt horizon from the future fields (by scrapers or graders). Leaching of "dry solonchak soils" requires large quantities of water—of the order of 7,000 to 10,000 m.^{3}/ha. If the ground-waters in the residual "dry solonchak soils" occur at a depth of 10–20 m. leaching may be done without drainage into the inner water-capacity of the ground. If the depth of the ground-water is less than 7–10 m. it is advisable to build the drainage system before washing.

Solonchak-like soils

Solonchak-like soils are those saline soils that contain in the root-horizons (i.e. within a metre) easily soluble toxic salts in concentrations from 0.3 up to 0.8 per cent, above which level crop plants come under stress. Crops of agricultural plants growing on solonchak-like soils are not quite normal, and are sometimes sparse. Yields are 30–60 per cent lower than on normal non-saline soils.

Depending on the chemical composition of the easily soluble salts present, solonchak-like soils, like solonchak soils, must be subdivided into soda, sulphate, and chloride soils.

The solonchak-like soils found in nature are usually of mixed chemical composition (i.e. soda-sulphate or soda-chloride ones, sulphato-chloride or chlorido-sulphate ones). All the negative properties, characteristic of solonchak soils, appear also in weakened form in solonchak-like soils. The higher the salt content, the smaller the natural fertility of solonchak-like soils.

As in the case of solonchak soils, it is necessary to subdivide the solonchak-like soils according to their hydrology and to the depth at which ground-water occurs.

Slightly saline meadow soils (contemporary, active ones). These are related to ground-waters by a capillary fringe through which mineralized water ascends from the ground-water table. The depth at which ground-waters occur in slightly saline meadow soils is usually 1.5–3 m. (varying in the course of different seasons). The ground-water mineralization in slightly saline meadow soils is always somewhat lower than in solonchaks and usually amounts to 0.5–3–5 gm./l. The highest proportion of easily soluble salts in slightly saline meadow soils is concentrated in the uppermost soil horizons (0–10–30 cm.).

During the rainy season, the majority of the easily soluble salts are shifted towards the depth reached by the atmospheric precipitation.

Reclamation and development of slightly saline meadow soils is much easier than that of solonchaks. Principal conditions of reclamation are leaching by about 2,000 to 3,000 m.^{3}/ha. of water, and the installation of a sparse network of deep drainage canals with intervals between them of up to 1,000 m. It is advisable, moreover, to bring gypsum, sulphur or acid products into the soda-meadow slightly saline soils, in order to neutralize their high alkalinity.

In dry agriculture and in pasture utilization, slightly saline meadow soils without irrigation are easily subjected to increased salt accumulation, and gradually pass into solonchaks. This occurs as a result of intensified evaporation of soil ground-waters, after destruction of the existing grass cover and mechanical pressure on the soil surface.

Residual solonchak-like soils (dry solonchak-like soils). This variety of solonchak soils is characterized by deep ground-water (i.e. 10–20 m. or more). Ground-waters may have a moderate or a high mineralization (10–30 gm./l.). The maximum of easily soluble salts is usually 30–50–100 cm. below the surface. The total of easily soluble salts at these depths may attain 0.3–0.8 per cent.

Residual slightly soda-saline soils are usually significantly alkaline, as expressed by morphological and chemical indices such as a columnar structure, the presence of exchangeable sodium and *p*H up to 9. In many cases residual slightly saline soils, easily soluble salts excluded, contain a gypsum horizon.

Residual alkaline-like soils are often mistaken for non-saline ones as a result of hurried field investigations. After gravity irrigation on residual solonchak-like soils (having no indications of a superficial salinization) salinization very often appears. This takes place as a result of a local redistribution of salt, and particularly after the rise of the ground-water level provoked by losses of irrigation waters.

Salt horizons, concentrated at 0.5–1 m. and lower, and also mineralized ground-waters, rise to the surface, and residual solonchak-like soils turn into active solonchak-like ones and into secondary active solonchaks. Most of the catastrophies connected with salinization of irrigated soils and known in scientific literature have taken place on residual solonchak-like soils as a result of an under-estimation of the salts, concentrated at a depth of more than 1 m.

With dry farming and with sprinkling irrigation residual solonchak-like soils do not require any reclamation. As a result of cultivation and sprinkling-irrigation they gradually desalinize.

Depending on the amount of easily soluble salts and on the depth of their occurrence, one distinguishes slight, medium and heavy solonchak-like soils.

The necessity of leaching out easily soluble salts and the danger of secondary soil salinization in the course of gravity irrigation through open canals on residual solonchak-like soils increase with a rise of the water-table, and with increased salinization in soils.

At the start, the development of residual solonchak-like soils may be carried out without drainage. Nevertheless, with gravity irrigation carried out from open canals, it is necessary to foresee the subsequent construction of drainage installations, aiming at a derivation of the saline ground-waters, ascending to the surface, after they have reached critical depths (2.5–3 m.).

According to experience obtained in the U.S.S.R. and in other countries, the average rate of rise of the ground-water level, in the presence of gravity irrigation, is 1–1.5 m. per year. If the depth at which ground-water occurs is 20–25 m. before irrigation, the need to install a drainage system only arises after about 12–15 years. If the depth of the ground-water is about 10–12 m., the need for drainage installations arises in the 5th–7th year after the beginning of gravity irrigation.

If easily soluble salts in quantities ranging from 0.5–0.8 per cent occur at small depths (25–50 cm.) in residual solonchak-like soils, one must, during the development period, carry out leaching by small quantities of water up to the internal water-capacity of the ground (without drainage). In such cases, with ploughing and deep subsoil scarifying, leaching quantities are 1.5–2 thousand $m.^3$/ha. It is advisable to leach under alfalfa crops. Under the alfalfa covering, during its irrigation and vegetation period, which lasts two or three years, deeper desalinization of the root-zone in the residual alkaline-like soils will occur.

Alkaline-soils solontsy

A peculiar form of barren, or feebly fertile, saline soil, broadly developed in steppe and forest-steppe regions, is called solonetz.

Solontsy are formed on such landscapes where the process of general carrying out of easily soluble salts from soils, soil-forming rocks and ground-waters is more or less expressed.

Ground-waters in solontsy always occur deeper than the possible height of the capillary zone above the water-table. Readily soluble salts in solontsy are never situated at the surface, as in solonchaks, but deeper, in the limits of 30–100 cm.

Three principal genetic horizons are characteristic for solonetz soils: *Horizon A*—eluvial, desalinized, humic, that has been submitted to processes of alkali degradation (solodization), and has symptoms of a foliated structure and a lightened composition; its thickness is 5–15–20 cm. *Horizon B*—illuvial, with a thickness of 5–10–20 cm.; of columnar prismoid structure, and dense consistence, with an alkali reaction (HCO_3' 0.1 per cent, *p*H about 9; exchangeable sodium in quantities exceeding 20–25 per cent of the exchange capacity). *Horizon C*—salty, carbonate, sulphate or chloride; mother rock, feebly altered by soil-forming, enriched by a variable quantity of salts.

High alkalinity and unsatisfactory hydrophysical properties (low permeability, hardness, lack of structure, bad aeration) result in a low natural fertility of solontsy. In arid years these shortcomings are manifested in an especially brutal fashion and the majority of agricultural plants develop badly or perish on solonetz soils. In natural conditions, on solonetz soil, dry-steppe xerophite wormwood associations and sometimes an ephemeral gramineous plant vegetation will appear.

Depending on their hydrogeological regime, solontsy are divided into two big groups.

Meadow solonchak-like solontsy. This group has slightly or moderately mineralized ground-waters that occur at a depth of 3–5–8 m. The capillary rise of ground-waters during dry years maintains the periodic introduction of exchangeable sodium into the absorbing complex of solontsy soil. The lower parts of Horizon B and Horizon C in the meadow alkaline-solonchak-like solonetz are always characterized by the more or less marked presence of easily soluble salts, sometimes of gypsum, and always of a significant quantity of calcium carbonate. According to the thickness of Horizon A, the solontsy are subdivided into crustal ones (in which Horizon A has a 3–5 m. thickness), and deep ones (in which Horizon A has a thickness $>$10–15 cm.).

The fertility of the second group of solonetz soils is much higher than that of the crustal ones.

Steppe solontsy. Soils of this group usually develop on high ancient river terraces or on watersheds, where ground-waters occur deeper than 20–30 m. and do not play any part in the contemporary soil-forming process.

Steppe solontsy are a residual form of the alkalinization process. Under the influence of digging animals, insects and, particularly, the root systems of plants, and also of calcium and potassium accumulating in the soils as a result of the small rotation cycle of ash substances, the steppe-solontsy gradually turn into developed zonal soils, proper to the particular territories (chestnut soils, chernozems, serozems). The degree of their alkalinity is always lowered. The thickness of the eluvial Horizon A is always sufficiently great (excluding eroded areas).

In dry farming or in irrigated agriculture, steppe-solontsy soil manifests its negative properties chiefly through bad physical properties and high alkalinity. To reclaim solontsy it is necessary to influence both these negative properties. Alkalinity is removed by bringing in gypsum, sulphur, calcium chloride or acid products. Deep ripping and the simultaneous addition of great quantities of organic substances in the form of manure into the soil or plant sowing contribute to the basic improvement of physical properties. As gypsum, sulphur and acid products are rather expensive, it has been proposed in the U.S.S.R., after adequate investigations, to reclaim solontsy by deep ploughing, combined with the mixing of gypsum-bearing and carbonate subsoil-horizons with the solonetz horizon. Deep ploughing to 35–50 cm. is achieved by special machines, the depth depending on the distribution of gypsum and carbonate horizons. Retention of snow and, particularly, irrigation after planting increase the efficiency of this method.

In the case of a high residual salinity in solontsy after planting, leaching is necessary. In certain cases it is necessary, during irrigation of such soils, to foresee drainage arrangements as is done during the irrigation of residual solonchak-like soils.

It is possible to improve steppe-solontsy by simpler means: by small doses of gypsum or physiologically acid fertilizers (superphosphate, ammonium sulphate) on a base of manure and of grass culture.

Alkaline-like steppe soils

Besides solontsy, there often occur in forest-steppes, steppes and desert-steppe regions of Eurasia alkaline "chernozems" (southern chernozem), alkaline-like chestnut soils (brown earths), alkaline-like steppe soils, alkaline-like serozems.

Alkalinity in these soils is expressed by less pronounced appearances of the same indices as are natural to solontsy: bad physical properties, dense sub-arable horizon, high alkalinity ($HCO_3 \gtrsim 0.08$ per cent; exchangeable sodium 10–15 per cent of exchange capacity; *p*H 8.5–9).

During moist years, crop plants on alkaline-like soil are not under particular stress: on the contrary, cereals often yield good crops of high quality grain. In the course of dry years crop plants on alkaline-like soils first suffer, then yield reduced crops of bad quality.

In the process of agricultural treatment in dry farming, and particularly in irrigation, the alkalinity of soils decreases. This is a result of the positive influence of physiologically acid fertilizers, manures, and root residues of plants; the effect of drying and freezing arable land; the influence of calcium contained in irrigation waters. Nevertheless, this process is slow.

As dry years occur rather often in steppes, it is advisable to improve alkaline-like soils so that the negative influence of droughts may be weaker and rarer. Deep treatment of alkaline-like soils, along with the creation of a thick arable and a friable sub-arable horizon, the application of greater doses of manure and of mineral fertilizers, and also correct grass plants in the crop rotation hasten the disappearance of alkalinity in such steppe soils and improve their properties. In the presence of adjoining cheap gypsum deposits, it is rational to bring into areas with alkaline-like soils small quantities of gypsum (1–3 t./ha.).

Takyrs

Takyrs and *takyr*-like soils are the names given to a peculiar variety of saline, utterly barren soils characteristic of deserts in Asia and North Africa.

Takyrs are soils formed during the process of desalinization of certain plains in hot desert conditions. They take the form of vast barren plains of clayey deserts with practically no vegetation.[1] In dry periods the polygonally cracked surface of the *takyrs* resembles a block pavement. After rainfall, owing to its non-permeability, the *takyr*, over-saturated with water, is transformed into an impassable low-water lacustrine swamp.

The surface of the *takyr* is covered by a dense, porous, clayey crust, 3–5 m. thick. Below the crust there is an horizon where the salt content may attain 0.5–1.5 per cent. Under the *takyr*, at a depth of more than 20–30 cm., spreads a saline feably-altered ancient alluvial rock. Ground-waters in *takyrs* occur at depths of more than 10–20–30 m.

The complete barrenness of *takyrs* may be explained by aridity, extremely unfavourable physical properties, high alkalinity (*p*H up to 9–10), high residual salinity of the subcrustal horizon, and an almost complete absence of both humus and the bacterial microflora usually found in soils.

The plain character of the surface and the great areas occupied by the *takyrs* make them very promising objects for irrigated agriculture in Asia and Africa. But their ploughing and irrigation without preliminary reclamation

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[1] *Takyr* in the Kazakh and Uzbek languages means naked, poor; this is near to the Arabic word *fakir*.

measures sometimes lead to negative results. As the *takyrs,* owing to their non-permeability, absorb irrigation water with difficulty, the ploughed and wetted surface dries up into a cemented, salt-impregnated clayey crust.

Among the *takyrs* one observes a great variety of physical and chemical properties, and also of differences of degree of *takyr* types.

On the basis of the experience of the Uzbeks and Turkmenians, and also of scientific investigations carried out during the 1950's in the U.S.S.R., a reclamation system, necessary for developing the *takyrs,* has been proposed. This system is complex, and includes measures: to improve the physical composition of the *takyrs* (i.e. by introducing sand into the soil in quantities of 300–500–700 t./ha.); to improve the structure and remove alkalinity (plantage ploughing to a depth of 35–50 cm., in order to mobilize gypsum-bearing horizons and the subjacent alluvium not touched by the *takyr*-forming process); for the removal of residual readily soluble salts from the root zone (leaching, after plantage, ploughing and silting by quantities of water of the order of 5,000–10,000 m.^{3}/ha.); for the creation in the *takyr* of an active biological regime (by introducing high doses of local organic fertilizers; sideration, etc.).

As *takyrs* have ground-waters occurring at depths of more than 10–20 m., washing and irrigation can also be carried out in the absence of drainage. Nevertheless, after the creation of large irrigation canals, covering vast territories, ground-water will gradually rise and it will be necessary to envisage, on irrigated *takyr* areas already developed, the installation of a drainage system 10–20 years after the beginning of irrigation, depending on the depth at which ground-water occurs and the efficiency of the irrigation system.

SECONDARY SALINIZATION OF IRRIGATED SOILS AND ITS PREVENTION

One describes as secondary salinization of irrigated soils a rapid process of transformation of formerly non-saline, or weakly saline, soils into solonchak-like soils and solonchaks with a partial or complete loss of natural fertility.

Processes of secondary soil salinization occur in newly built irrigation systems with low efficiency several years after the beginning of work. Contemporary irrigation canals, without any hydro-proofing, work with an efficiency of about 0.3–0.6. There occur also great losses of irrigation water on the fields. The waters lost in the irrigation system replenish the reserves of ground-waters and provoke a rise in their level, at first near great irrigation canals, and later throughout the irrigated area. Nearing the surface, the ground-waters dissolve the salts contained in the subsoil layers of the ground, and increase their own mineralization.

After the ground-water table has attained a level higher than the critical one, a number of serious changes occur in the irrigation area: fertility of soils is lost and crop plants perish; plantations of fruit and other trees perish; it is difficult to use machines on the fields because of excessive humidity; *pisé* and even brick buildings are demolished; the state of roads becomes worse; malaria develops, etc. In time, along large and medium irrigation canals, zones of desalinized ground-water and soils are formed. A more or less stable irrigated agriculture exists on these zones, and 40–60 per cent of the irrigated territory is abandoned. Such phenomena are known in several irrigation areas in Central Asia, the Caucasus, India, Iran, Iraq, United Arab Republic (Region of Egypt) and the U.S.A.

The speed with which the ground-water level rises after work is started on the irrigating system depends on its efficiency, on water utilization discipline in the fields, on the initial depth of ground-waters, and on the natural drainage conditions. The worse the conditions of natural drainage (e.g. dry and marine deltas, lowlands without run-off and formed by clayey, slightly permeable, sediments), the higher the ground-water level before irrigation, and the greater the losses in water from the irrigation system, the higher will be the rate of rise of the ground-water level, reaching sometimes 2–3 m. per year.

The average speed, in the existing types of irrigation systems (canals without hydro-isolation, gravity irrigation), is about one metre per year.

Preventive measures against secondary salinization occurring as a result of the rise in ground-water levels are: strengthening water utilization discipline in every possible way; raising as much as possible the efficiency of the system (up to values 0.8–0.9, by means of monomolecular films), closing irrigation canals in seasons when waterings do not take place; creating in irrigation systems, and particularly along canals, belts of trees to ensure biological drainage; changing, wherever possible, gravity irrigation into sprinkling.

By applying such measures it is possible to prevent secondary salinization in areas possessing natural drainage (i.e. on high alluvial terraces, plains and foothills; watershed plains with permeable rocks—sand, pebble beds).

In areas possessing no natural drainage, preventive measures may greatly delay (for 20–50 years) the starting of salinization processes caused by the rise of ground-waters.

The liquidation of existing secondary and natural salinization must be based upon simultaneous operations: (a) carrying out of the system of preventive measures mentioned above; (b) creating an extensive deep drainage network in order to lower the ground-water level and to increase the speed of its circulation; (c) carrying out a system of measures for the desalinization of soils (leaching, ground-water desalinization, etc.).

In some cases secondary salinization may be caused by a high mineralization of irrigation waters. According to the experience of the Soviet Union, irrigation water with a mineralization lower than 1 gm./l. is quite favourable, and holds no threat of developing processes of salt-accumulation through irrigation. With a good water exchange, irrigation water with a salt concentration of not more than 5–6 gm./l. is physiologically harmless for plants. Stress on crop plants is caused by water containing salts in concentrations of 10–12 gm./l. and more. Nevertheless, irrigation waters with a mineralization higher than 2–3 gm./l. are already a serious source of salt-accumulation, and with 5–8 gm./l. they may provoke a rapid salinization of the irrigated soils.

In hot dry climatic conditions, when 5–10–15 waterings are carried out each year, waters with the indicated degrees of mineralization bring into the irrigated fields great quantities of salts (up to 100–200 t./ha. yearly). Concentration of soil solutions in fields irrigated by mineralized waters must not attain toxic values (15–20 gm./l. ~~and more~~), at which the crop diminishes strongly, or perishes. This is why irrigation by mineralized waters must be accompanied by leaching, i.e. maintaining the downward flow and carrying the accumulating salts out of the root zone and only on the basis of intensive drainage systems that guarantee a free circulation and a complete replacement of soil solutions by fresh circulation and a complete replacement of soil solutions by fresh irrigation waters.

In general one may consider (see figs. 2 and 3) that: (a) when mineralization of irrigation water is 2–3 gm./l., it is necessary to effectuate leaching once each year, in order to remove the salts remaining after irrigation; (b) when mineralization of irrigation water is 4–5 gm./l., it is necessary to leach after 4–5 normal waterings; (c) when mineralization of irrigation water is 7–8 gm./l., each second or third watering must be a leaching; (d) when mineralization of irrigation water is 10–12 gm./l., it is necessary to introduce the practice of increasing the frequency of waterings, using quantities exceeding the water-holding capacity of the soil, and assuring evacuation by the use of a closely situated, deep, and irreproachably working drainage system.

Failure to observe these rules will lead to the development of active secondary salinization, accompanied by grievous consequences.

RECLAMATION OF SOLONCHAK-LIKE SOILS AND OF SOLONCHAKS

Successful development and irrigation of solonchak-like soils and of solonchaks are possible only when desalinization of the arable and root horizons of soils brings down the salt content, during the vegetation period, to 0.3–0.4 per cent or even less, and when desalinization of ground-water brings down the values to less than 2–3 gm./l.

In those cases in which solonchak soils are of the contemporary group (i.e. when ground-waters are high), washing in order to remove the salts must be carried out by means of drainage systems of the horizontal or vertical type.

The amount of water necessary for washing out salts from solonchak soils during the period of their initial development will be the greater, the greater is the degree of salinization of the soil, the higher the ground-water mineralization, the nearer to the surface the salts occur and the more clayey the mechanical composition of soils and subjacent rocks.

The dependence of the increased water quantities—necessary for the leaching of solonchaks—on the degree of their salinization is shown in a generalized form in fig. 4.

In an approximate form, the relationship existing between the salinity of soils and the quantity of water to be used for leaching out the salts might be shown by the following equation:

$$y = n^{400}\, x \pm 100$$

$$n = 0.5\text{–}2.0$$

In this equation, y is the quantity of water to be used for leaching expressed in millimetres of depth of water; x is the average of salinity of the soil expressed in per cent for the depth of 1–2 m. in this particular section of reclaimed field; n is the coefficient depending on the permeability of the soil and on the depth of occurrences as well as on the degree of salinity of ground-water in this particular section of the reclaimed field. On the average, the coefficient n is 0.5–2.0; for sandy soils 0.5; for loam 1.0; for clay 2.0; for deep-located ground-water 1.0; and for high located saline ground water 2.0.

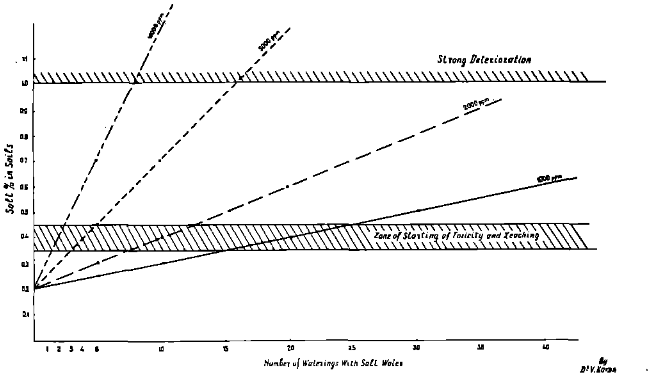

FIG. 2. Salinization of soils due to irrigation by salt water.

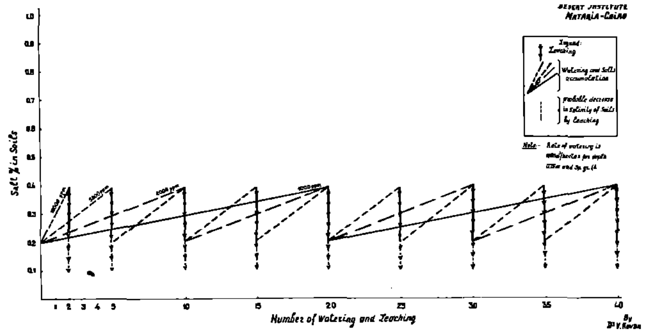

FIG. 3. Regulating the salinity of soils when irrigating with saline water.

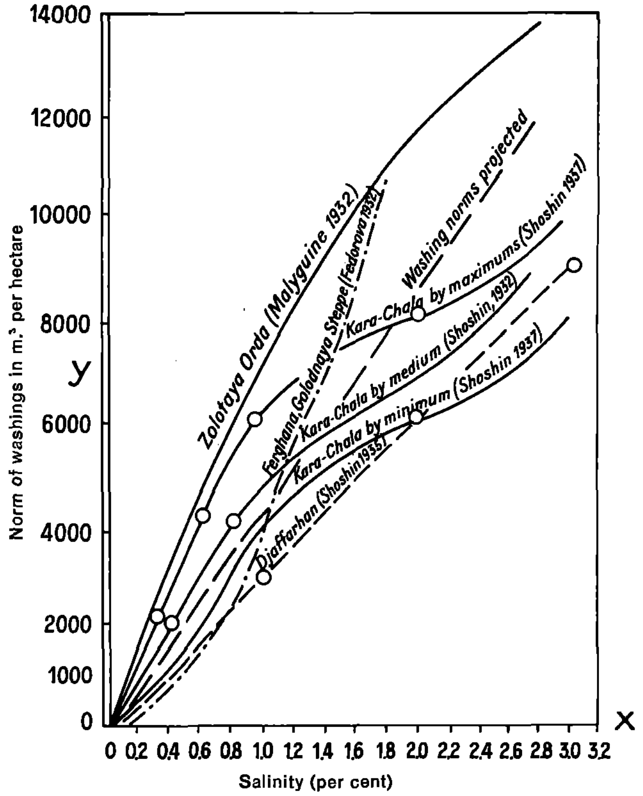

FIG. 4. Dependence of washing norm on salinity according to data obtained from different investigations (V. R. Volobueff [29]).

For calculating approximately the quantity of water to be used for leaching it is necessary to know the texture of the soils, the degree of salinity of soils and sub-soils, the depth and salinity of ground-water.

If the quality of the leaching water needed to reclaim strong solonchaks reaches or exceeds 12,000–15,000 m.³/ha., it is advisable to combine the leaching of solonchaks with irrigated rice crops, giving waterings of 20,000–25,000 m.³/h. and thus guaranteeing (on the basis of drainage) a rapid and efficient desalinization of soils.

As shown by Soviet experience, it is advisable to carry out leaching of solonchaks by quantities of water of the order of 5–10–12 thousand m.³/ha. during the autumn or the winter season.

For the germination of seeds and crops on solonchak-like soils the quantities of irrigation water necessary are much less—1,000–3,000 m.³/ha.

The leaching of salts from solonchaks and from solonchak-like soils is very slow and is accompanied by a renewal of salinity towards autumn (owing to evaporation and transpiration of soil ground-waters). Therefore, one has generally to renew each year, or periodically during a long time, the leaching or autumn-winter waterings.

Soils with mineralized ground-waters and inclined to salinization, but protected by artificial drainage installations that work efficiently, must be watered in order to liquidate completely the salinization processes (i.e. to maintain moisture in the fields between waterings with the limits of 80–100 per cent relative moisture).

Successful washing out of salts and the maintaining of desalinization in formerly saline soils after leaching are possible only when efficient drainage installations exist. From scientific and practical experience acquired in the U.S.S.R. it is permissible to think that at the present stage an horizontal closed drainage system is economically feasible. It is an effective measure for reclaiming irrigated saline soils in order to grow valuable crops: cotton plants, tobacco, sugar-beet, rice, etc.

Horizontal drainage for the reclamation of saline soils must achieve the following aims: (a) lowering of the saline ground-water level by 30–40 cm. below the critical depth; (b) organization of a sufficiently efficient circulation of soil ground-waters for mineralized solutions to be gradually replaced by non-saline ones; (c) organization of a general run-off of drainage and ground-waters in the absence of natural drainage in the area; (d) maintenance of a stable favourable water-salt-soil regime, thus obviating the danger of renewed salinization.

Most important in drainage work is the stage when leachings are carried out. Great quantities of water appear in the irrigation system, the ground-water level rises considerably and it is necessary within a short time to divert great masses of salt solutions.

Two essential periods are to be distinguished in the work of drainage systems:

The reclamation period. During this period, drainage systems are used for washing solonchaks and solonchak-like soils and for diverting mineralized ground-waters. Within this period two stages can be distinguished:

1. The desalinization of the root soil horizon up to optimal values. During this period (2–3 years) is carried through the most heavy work of leaching solonchaks by large quantities of water, alone or in combination with irrigated rice crops. Drainage systems at this period divert 60–80 per cent of the waters brought on to the fields for leaching. During this period the irrigated fields are used for transitory crops that have high salt tolerance, such as rice, *djougara* (a kind of millet), barley, grasses, etc.
2. The desalinization of ground-waters under former solonchaks down to optimal concentrations (less than 3–2 gm./l.). Until ground-waters under former solonchaks are desalinized to an optimal degree to a depth of a few metres, a renewal of soil salinization is inevitable. The desalinization of ground-waters under former solonchak soil is a long process, requiring much time and a great deal of water. During this stage the desalinization of solonchaks and of ground-waters is undertaken on the basis of a normal utilization of irrigated lands, on which the main types of plant are grown. With the help of waterings a relative moisture must be maintained that remains within the 80–100

per cent range. For the leaching of salts it is necessary to carry out, periodically, autumn-winter waterings with quantities of 1,000–3,000 m.^{3}/ha. During this stage the drainage systems divert about 25–30 per cent of the irrigation waters that are brought into the fields. The desalinization of ground-waters down to optimal quantities occurs after not less than 15–20 years of the reclamation-irrigation work.

The exploitation (normal) period. This period is established in the reclamation-irrigation system as a result of the ending of the desalinization processes of soils and ground-waters. After their mineralization has fallen below the critical depth, ground-waters represent a great agricultural asset, and are utilized by agricultural plants at the same time as irrigation waters. During this period of the irrigation system's work, it is possible to lower the irrigation quantities and the number of waterings to 30–50 per cent, as compared with the preceding period. Part of the drainage canals may be cut off but, nevertheless, the drainage systems as a whole must, as formerly, function irreproachably, assuring the "salt ventilation" of the irrigation system and diverting about 5–10 per cent of the total of irrigation waters brought into the system. During this period, with the help of sluicing of the drainage system, it is possible to maintain the level of desalinized ground-waters much higher in order that sub-irrigation and the meadow soil-forming process be maintained; under these conditions soil fertility and crops attain their maximum values.

Along with "salt ventilation", drainage systems may at this stage (after a complete desalinization of ground-waters) ensure subsoil irrigation.

The foregoing survey of the principles of the theory and practice of reclaiming and developing saline soils in the arid zone are based upon work carried out over a long period, and under the author's guidance, in the laboratory for the development and reclamation of saline soils of the Soil Institute, U.S.S.R. Academy of Sciences; and also upon an analysis and generalization of scientific and practical material of the Ministry of Agriculture of the U.S.S.R.

The scientific works published in the Soviet literature as primary basic material on these problems are cited in the bibliography at the end of this article.

RÉSUMÉ

Principes de la théorie et de la pratique de l'amendement et de l'utilisation des sols salins dans les régions arides (V. A. Kovda)

Il convient d'établir les distinctions ci-après, du point de vue de la géographie et de la géochimie, entre les divers types de formation des sols salins:

1. Types continentaux d'accumulation de sels: cycles primaires d'accumulation (par exemple en Mandchourie et en Mongolie) et cycles secondaires (par exemple au Sin-Kiang et en Iran).
2. Types côtiers d'accumulation de sels.
3. Types d'accumulation de sels propres aux deltas.

Le facteur qui actuellement contribue le plus, et de la façon la plus directe, à la formation des sols salins est le processus d'évapotranspiration de l'eau de la nappe phréatique, lorsque l'écoulement ne s'effectue pas ou s'effectue au ralenti. Sous un climat aride, les masses de sels accumulées dans les sols, les roches sédimentaires et les eaux souterraines peuvent subsister très longtemps.

Pour comprendre le mécanisme de l'accumulation des sels et lutter contre la salinisation, il faut tenir compte des constantes édapho-hydrologiques ci-après: *a*) *minéralisation critique de la nappe phréatique*; *b*) profondeur critique de la nappe phréatique; *c*) seuil de toxicité physiologique des sels.

La classification des sols salins de l'Eurasie comporte les divisions ci-après:

1. Les croûtes salines, comprenant: *a*) les croûtes calcaires; *b*) les croûtes gypseuses; *c*) les croûtes salines proprement dites.
2. Des sols salifères, comprenant: *a*) les sols salifères à carbonates; *b*) les sols salifères à sulfates; *c*) les sols salifères à chlorures; *d*) les sols salifères à nitrates.

Pour amender les sols salifères, il importe de connaître exactement leurs caractéristiques hydrologiques du point de vue des nappes phréatiques. A cet égard, on peut distinguer les sols salifères actifs (contemporains) des sols *résiduels* où les nappes phréatiques se trouvent à des profondeurs dépassant 7 à 10 mètres.

3. Des sols salifères comprenant: *a*) les sols de prairies salifères; *b*) les sols résiduels salifères.
4. Les "solonetz" (sols alcalins) comprenant: *a*) les sols de prairies salifères; *b*) les solonetz de steppe.
5. Les sols de steppe salifères.
6. Les "takyry".

Lorsqu'on étudie les processus actuels de salinisation du sol et les moyens de les prévenir, il est nécessaire d'examiner la question de la *salinisation* secondaire des sols irrigués. Des phénomènes de cet ordre ont été constatés dans les régions irriguées de l'Asie centrale, du Caucase, de l'Inde, de l'Iran, de l'Irak, de l'Égypte et des États-Unis d'Amérique.

Parmi les mesures propres à empêcher la salinisation secondaire associée à l'élévation du niveau hydrostatique, il convient de citer la discipline dans l'utilisation de l'eau, et un rendement plus efficace du système grâce à l'emploi de vannes étanches, à la fermeture des canaux pendant les saisons où l'on ne pratique pas l'irrigation, à la plantation d'arbres le long des réseaux et canaux d'irrigation, etc.

Pour éliminer la salinisation secondaire, il faut:
1. Appliquer un ensemble de mesures préventives;
2. Aménager un important réseau de drainage afin d'abaisser le niveau de la nappe phréatique et d'accélérer son écoulement;
3. Mettre au point une série de techniques de dessalement des sols.

L'expérience acquise dans le domaine scientifique et technique permet de penser qu'au stade actuel, un système de drainage clos horizontal est économiquement acceptable et assure très efficacement l'amélioration des sols salins en cours d'irrigation.

Ce drainage horizontal doit viser les objectifs suivants:
1. Abaisser le niveau des nappes phréatiques au-dessous de la profondeur critique;
2. Organiser une circulation des eaux de surface et souterraines assez active pour que les solutions minéralisées soient remplacées graduellement par des eaux douces;
3. Remédier à l'absence d'écoulements sur le territoire considéré, et organiser un écoulement général en détournant les eaux de drainage et les eaux souterraines;
4. Maintenir constamment un bilan favorable de l'eau et des sels, de façon à prévenir le risque d'une nouvelle salinisation.

Il y a lieu de distinguer deux phases dans le fonctionnement des réseaux de drainage:
1. La période d'amendement du sol;
2. La période d'exploitation normale.

Les principes et les méthodes concernant l'amendement et l'utilisation des sols salins dont traite le présent rapport reposent sur l'expérience acquise par l'auteur au cours de travaux effectués pendant de nombreuses années au Laboratoire d'étude sur l'origine et l'amendement des sols salins (Institut de pédologie), ainsi que sur l'analyse de la documentation scientifique et technique produite par le Ministère de l'agriculture de l'URSS, et sur les conclusions générales qu'on peut en tirer.

DISCUSSION

M. L. Dewan. (1) What factors does the critical mineralization of ground-water take into consideration?

(2) Could the speaker dilate on occurrence of "Mg solonetz" soils in the U.S.S.R.; under what conditions are these soils found to occur, and what is the difference in their physico-chemical properties as compared with Na solonetz soils?

(3) Would the author please define the terms "deluvial" and "proluvial" as used in the Soviet soil literature, as these terms are not used in the soil dictionaries—even the one published by FAO?

V. A. Kovda. (1) Critical mineralization of ground-waters is the highest (non-toxic, for plants) concentration of soluble salts in ground-waters of hydromorphic soils for which the process of salinization of irrigated reclaimed (or natural meadow) soils does not exist; on the average this concentration is 2–3 gm./l. (See page 202.)

(2) Some of the alkaline ($NaHCO_3$ and Na_2CO_3) saline soils of U.S.S.R. contain $MgCO_3$ (Transcaucasian). The toxicity of $MgCO_3$ is less than the toxicity of sodium carbonate.

(3) Deluvial deposits—the deposits formed on the slopes by means of local surface water run-off (waters of snow and rains).

Proluvial deposits—the deposits formed by activity of temporarily existing rivers and streams (usually on the plains at the foot of the mountains).

M. Ayazi. (1) What kind of drains are you using mostly in your country for laterals? Open or closed drains?

(2) Somewhere they have found that if they let the soil dry out after leaching, the infiltration rate of soil will increase and the leaching will be much easier in the future. But you have another opinion. Will you explain a little more about your opinion.

V. A. Kovda. (1) In the U.S.S.R. drains of the open type are being constructed.

(2) Before leaching of salts from the salted soil it is better to have dry soil; the effect of leaching in this condition is much greater.

To prevent a renewal of salinity after leaching, it is better to maintain the high moisture of irrigated soil (before watering not less than 70–75 per cent of water capacity). In that case, in irrigated reclaimed soil (saline in the past), a downward movement of salt solutions dominates, the process of desalinization of the soil is accelerated and the fertility of the reclaimed soil is more stable.

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PREDICTION OF THE EFFECTS OF IRRIGATION WATERS ON SOILS[1]

by

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All irrigation waters contain more or less dissolved constituents. Because of the presence of these constituents the application of irrigation waters to soils may markedly alter their properties for the growth of plants. The changes in soil properties which take place upon irrigation may be either beneficial or detrimental, depending upon the composition and concentration of the dissolved constituents in the water, and the original characteristics of the soil. Sometimes, the application of a water results in the eventual correction of undesirable conditions originally present in soils. However, irrigation water often has an adverse effect upon soil properties and productivity. The continued use of some irrigation waters has necessitated the abandonment of formerly productive soils in many parts of the world. Thus the ability to predict the effects of irrigation waters on soils is of great importance in irrigation agriculture.

The dissolved constituents of irrigation waters consist for the most part of the cations—sodium, calcium and magnesium—and the anions—chloride, sulphate and bicarbonate. Constituents which usually occur in only minor or trace amounts are potassium, carbonate, nitrate, silicate and boron. Of the minor constituents, only boron because of its extreme toxicity to plants at relatively low concentrations ordinarily deserves special consideration in predicting the effect of waters on soils. The cationic constituents are adsorbed and released by the surfaces of soil particles in accordance with the principles of cation exchange, whereas the anionic constituents undergo no appreciable adsorption. Boron, which probably occurs in most waters as almost completely undissociated boric acid, is adsorbed to some extent.

The principal direct effects of irrigation waters on soils may be grouped into two categories: (a) effects upon the concentration of the soil solution; (b) effects upon the composition of the dissolved and adsorbed constituents. The indirect effects are many and varied. Some of the most important adverse effects are the decreased absorption of water by plant roots as the concentration of the soil solution increases, the deterioration of the physical condition of soils as a consequence of the adsorption of sodium, and the specific toxicity of some constituents such as boron to plants. The chief beneficial effects of the application of irrigation waters, other than the supplying of water and some mineral nutrients to plants, are the leaching of accumulated salts and the improvement of soil structure through the replacement of adsorbed sodium by calcium and magnesium contained in the water.

CONCENTRATION OF THE SOIL SOLUTION

The relation between the concentration of total dissolved constituents in the irrigation water and that in the soil solution of the root zone is complex, being determined primarily by the fraction of the applied water which over a period of time passes through the root zone, and secondarily by the water content of the soil. Influences which are usually minor are also brought into play through the precipitation of constituents in the soil and the removal of constituents in harvested crops. The fraction of applied water which passes through the root zone over a period of time is related to the amount of dissolved constituents in the root zone, whereas the water content of the soil determines the volume of water in which the constituents are dissolved. For a given amount of salt in the soil the relation between the concentration of the soil solution and the water content is inverse. The fraction of applied water which passes the root zone and the water content of the soil are, in turn, influenced by several factors, including the frequency and amount of water application in relation to that lost to the atmosphere by evapotranspiration, the position of the ground-water table, and the permeability of the soil. Thus, for a given irrigation water the concentration of the soil solution may vary greatly, depending upon water management practices, and soil and drainage conditions.

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[1] Contribution from the U.S. Salinity Laboratory, Soil and Water Conservation Research Branch, Agricultural Research Service, U.S. Department of Agriculture, Riverside, California, in co-operation with the 17 western states and the Territory of Hawaii.

The pertinent question is therefore: What depth of irrigation water, having a given concentration, should be applied to maintain the mean concentration of the soil solution over a period of time at a prescribed level?[1] The leaching requirement concept developed independently by Klintworth [10][2] and the staff of the U.S. Salinity Laboratory [14] is useful in this regard. The concept is based on the principles of salt-balance and steady-state water-flow rates. If V_i and V_d are volumes of irrigation and drainage water, respectively, having corresponding salt concentrations C_i and C_d, S_s is the quantity of salt precipitated in the soil and S_c is the quantity of salt removed by the harvested crop, then

$$V_iC_i - V_dC_d - S_s - S_c = 0 \qquad (1)$$

Assuming no precipitation of salts, no removal of salts by the harvested crop and uniform areal application of water, this equation reduces to

$$D_d/D_i = C_i/C_d \qquad (2)$$

where D_d and D_i are volumes per unit of area or equivalent depths of drainage and irrigation waters, respectively. The leaching requirement (LR) is defined as the ratio of the equivalent depth of drainage water to the depth of irrigation water, D_d/D_i, that is required to maintain a given soil solution concentration at the bottom of the root zone. As the concentration of the soil solution at the bottom of the root zone equals the concentration of the drainage water, one may write

$$LR = D_d/D_i = C_i/C_d \qquad (3)$$

Thus the leaching requirement may be calculated from knowledge of the concentration of the irrigation water and the permissible concentration of the drainage water.

In using equation (3) the depth of root zone, the water content of the soil, cation exchange reactions, soil permeability and drainage conditions are not directly involved, providing the permeability and drainage will permit the specified leaching. If rain-water as well as irrigation water is involved an adjusted, concentration for applied water, $C_{i(\text{adj})}$, should be substituted for C_i. The adjusted concentration is calculated by the equation

$$C_{i(\text{adj})} = (D_rC_r + D_iC_i)/(D_r + D_i) \qquad (4)$$

where D_r and C_r are respectively the depth and concentration of rain-water.

The increase in salt concentration from that of the irrigation water to that of the drainage water is largely determined by losses of water by evapotranspiration. The depth of irrigation water entering the soil, D_i, is related to the depth lost by evapotranspiration, D_e, and the depth of drainage water, D_d, by the equation

$$D_i = D_e + D_d \qquad (5)$$

Substitution of equation (2) into equation (5) gives an equation for expressing depth of irrigation water in terms of depth of water lost by evapotranspiration and the concentrations of the irrigation and drainage waters, viz.

$$D_i = D_e\left(C_d/(C_d - C_i)\right) \qquad (6)$$

To illustrate the use of equation (6) let us assume that it is desired to grow a moderately salt-tolerant crop with irrigation water having a total salt concentration of 10 meq./l. Let us assume further that the equivalent depth of water lost by evapotranspiration in growing the crop is 60 cm., and that the crop can tolerate a salt concentration of 80 meq./l. at the bottom of the root zone. Substituting the appropriate values in the equation gives a value of 68.6 cm. for the depth of irrigation water which should be applied during the growing season to prevent the concentration of the drainage water from exceeding 80 meq./l. The leaching requirement on a percentage basis, as calculated by equation (3), is 12.5.

In using equations (3) and (6) no precipitation of salts in the soil, no removal of salts by the harvested crop, and uniform application of water are assumed. In practice, the precipitation and removal of salts tends to make values for the leaching requirement, calculated by equation (3), and the depths of irrigation water, calculated by equation (6), high, whereas non-uniform application of water tends to make them low. Thus errors which result from the assumptions made are compensatory.

COMPOSITION OF DISSOLVED AND ADSORBED CONSTITUENTS

In predicting the effects of irrigation waters on the composition of the dissolved and adsorbed constituents of soils, it is useful to consider the irrigation of a soil to be a column process involving the adsorption and exchange of constituents during the downward flow of water. After irrigation water has been allowed to flow through a soil profile for some time, three zones in the profile may usually be distinguished: (a) an upper zone in which the adsorbed constituents are in equilibrium with the irrigation water and the composition of the soil solution is the same as that of the irrigation water; (b) a lower zone in which the composition of the dissolved and adsorbed constituents has not yet been affected by the irrigation water; (c) an intermediate zone in which adsorption and exchange are taking place and the composition of the dissolved and adsorbed constituents ranges between that of the upper and lower zones. With continued application of irrigation water the upper zone increases in depth and the intermediate zone shifts downward. It should be understood, of course, that in practice the situation described above is never completely realized owing to various disturbing influences such as concentration of the soil solution and the precipitation of constituents as a result of loss of water through evapotranspiration.

For prediction purposes, two kinds of information are needed: (a) the approximate composition of the adsorbed constituents when the soil is in equilibrium with the irrigation water, and (b) the depth of irrigation water that

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[1] It is understood, of course, that the concentration can never be appreciably less than that of the irrigation water, unless the soil is leached with rain water.

[2] The figures in brackets refer to the bibliography on page 222.

must be applied to equilibrate the soil to a given depth with various constituents of the irrigation water.

Cation equilibria

As indicated previously, the cations in irrigation waters undergo exchange reactions with the cations adsorbed on the surfaces of soil particles. If given sufficient time, an equilibrium between the adsorbed cations and those in the soil solution is attained. Eriksson [7] has derived a cation-exchange equilibria equation that shows the fraction of the cation exchange capacity satisfied by adsorbed monovalent cations as a function of the concentrations of monovalent and divalent cations in the surrounding solution. The equation in simplified form for a soil containing sodium, calcium and magnesium is:

$$\frac{q_{\mathrm{Na}}}{Q_{\mathrm{Na}}} = \frac{r}{f\Gamma\sqrt{\beta}} \sinh^{-1} \frac{f\Gamma\sqrt{\beta}}{r + 4v_c\sqrt{c_{\mathrm{Ca+Mg}}}} \qquad (7)$$

in which $\frac{q_{\mathrm{Na}}}{Q_{\mathrm{Na}}}$ is the fraction of the cation exchange capacity satisfied by adsorbed sodium, Γ is the surface charge density of the soil in meq./cm.^{2}, f is a correction factor for Γ and is related to the radii of the specific cations involved in water, $r = c_{\mathrm{Na}}/\sqrt{c_{\mathrm{Ca+Mg}}}$ (mol./l.)$^{\frac{1}{2}}$ where c_1 and c_2 are the solution concentrations of sodium and calcium + magnesium, respectively, $\beta = 1.06 \times 10^{15}$ cm./mmol. at 25°C. and v_c is a symbol having a value of approximately 1.

Bower [1] found that Eriksson's equation satisfactorily describes cation-exchange equilibria in soils of arid zones, and that the value of f for soils containing sodium, calcium and magnesium is about 1.4. The surface charge densities of many soils of arid zones as calculated from cation exchange capacity determinations and surface area measurements by ethylene glycol retention [3] range between 1.7 and 1.9 × 10^{-7} meq./cm.^{2}, but have been observed to be as low as 1.1 × 10^{-7} meq./cm.^{2} and as high as 2.5 × 10^{-7} meq./cm.^{2}. Figure 1 shows the relation between the ratio $c_{\mathrm{Na}}/\sqrt{c_{\mathrm{Ca+Mg}}}$ for equilibrium solutions and the fraction of the cation exchange capacity satisfied by sodium $\left(\frac{q_{\mathrm{Na}}}{Q_{\mathrm{Na}}}\right)$ at three surface charge densities, as calculated by Eriksson's equation. A value of 0.004 mol./l. for $c_{\mathrm{Ca+Mg}}$ was assumed. The value of $c_{\mathrm{Ca+Mg}}$ may vary considerably without affecting the relation appreciably. As the ratio $c_{\mathrm{Na}}/\sqrt{c_{\mathrm{Ca+Mg}}}$ for the irrigation water equals that of the soil solution when the water is in equilibrium with the soil, the extent to which a water will saturate the soil exchange material with sodium may be predicted by the use of either equation (7) or fig. 1, from the sodium and calcium + magnesium concentrations of the water and the surface charge density of the soil. For most soils a surface charge density of 1.8 × 10^{-7} meq./cm.^{2} can be assumed.

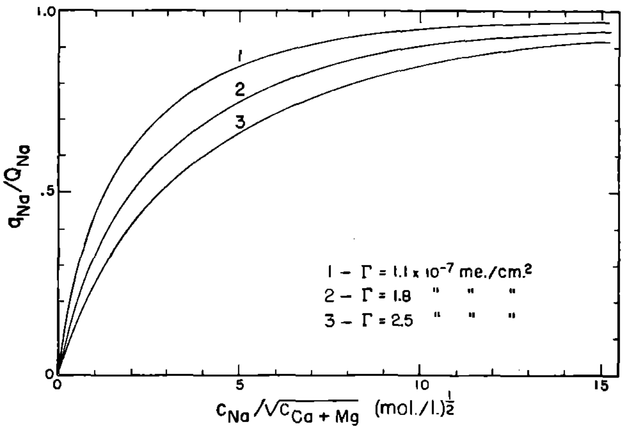

FIG. 1. Relation between the concentrations of sodium and calcium + magnesium for equilibrium solutions $(c_{\mathrm{Na}}/\sqrt{c_{\mathrm{Ca+Mg}}})$ and the fraction of the cation exchange capacity satisfied by sodium $\left(\frac{q_{\mathrm{Na}}}{Q_{\mathrm{Na}}}\right)$ at three surface charge densities (Γ) as calculated by Eriksson's equation.

Thorne and Thorne [13] and Wilcox[1] have determined the fraction of the cation exchange capacity saturated with sodium for surface soils from various sources where the soil had been irrigated with water of known composition for considerable periods of time and it seemed highly probable that the soil was in equilibrium with the water. The relation between the $c_{\mathrm{Na}}/\sqrt{c_{\mathrm{Ca+Mg}}}$ ratio of the irrigation water and the fraction of the cation exchange capacity saturated with sodium for the soils are indicated by the data points in fig. 2. The curves in the figures are the theoretical relations between the two variables calculated by Eriksson's equation for the upper and lower limits of surface charge densities observed in soils. As a very high percentage of the data points fall between the two theoretical curves it is apparent that Eriksson's equation has considerable value for predicting the effects of irrigation waters on the composition of the adsorbed cations in soils.

Boron equilibria

When irrigation water containing boron is allowed to flow through soil some of the boron is adsorbed by the soil until the adsorbed boron and the dissolved boron at the concentrations of the irrigation water and the soil solution are in equilibrium. If water having a lower concentration of boron is then applied desorption of boron occurs until a new equilibrium between dissolved and adsorbed is established.

Hatcher and Bower [8] found that over limited concentration ranges the equilibrium between dissolved and adsorbed boron in soils of arid zones can be expressed by Langmuir's adsorption equation, viz.

$$q_{\mathrm{B}} = (\mathrm{K}Q_{\mathrm{B}}c_{\mathrm{B}})/(1 + \mathrm{K}c_{\mathrm{B}}), \qquad (8)$$

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[1] L. V. Wilcox, unpublished data, U.S. Salinity Laboratory.

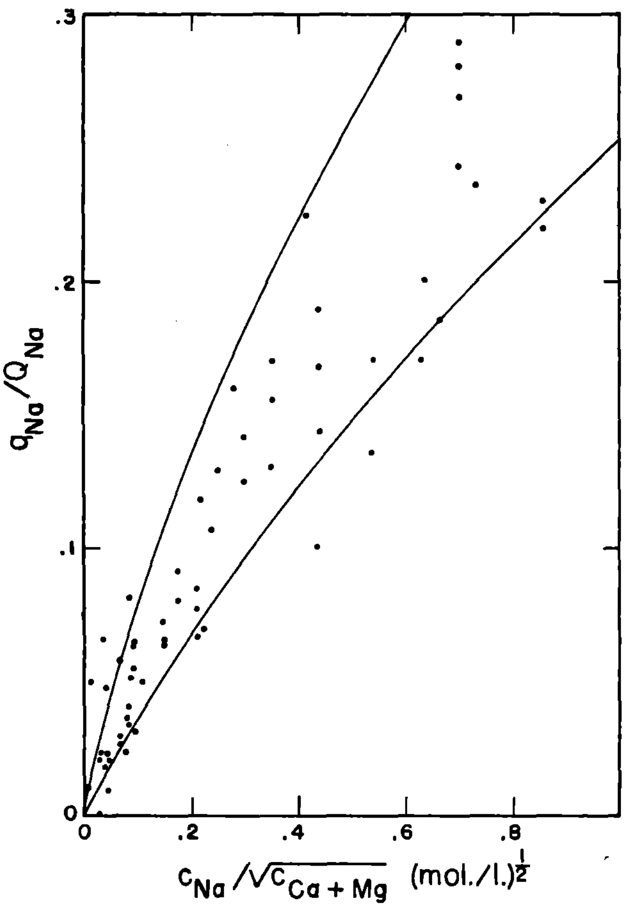

FIG. 2. Relation between the sodium and calcium + magnesium concentrations of irrigation waters $\left(c_{Na}/\sqrt{c_{Ca+Mg}}\right)$ and the fraction of the cation exchange capacity of soils irrigated with the waters saturated by sodium $\left(\frac{q_{Na}}{Q_{Na}}\right)$. The upper and lower curves are theoretical relations for surface charge densities of 1.1×10^{-7} and 2.5×10^{-7} meq./cm.^{2}, respectively.

where K is the adsorption equilibrium constant, Q_B the total boron adsorptive capacity, and q_B and c_B are the adsorbed and dissolved concentrations of boron, respectively. Values of K and Q_B for a given soil may be determined experimentally by adding a series of boron solutions of varying concentration to sub-samples of the soil and determining the equilibrium concentrations of dissolved (c_B) and adsorbed (q_B) boron. When c_B/q_B is plotted against c_B an approximately linear isotherm is obtained over limited concentration ranges. The constant K is obtained by dividing the slope of the isotherm by its intercept, while the capacity Q_B is the reciprocal of the slope of the isotherm. When adsorbed and dissolved boron concentrations are both expressed in mg./gm. the value of the constant K for the solution concentration range 0–0.008 mg./gm. has been found to be about 60 ml./mg. Values of Q_B vary but they correlate positively with the fineness or surface area of the soil.

Hatcher *et al.*[1] have obtained information which indicates that plants respond to the boron concentration of the soil solution and are not influenced directly by the amount of adsorbed boron present. As the boron concentration of the soil solution is equal to that of the irrigation water when the soil and water are in equilibrium, the effects of boron in irrigation water on plant growth after equilibrium is attained can be predicted directly from the boron concentration of the irrigation water.

Dynamics of cation exchange and boron adsorption

The composition of an irrigation water may be such that its effect on soils in a state of equilibrium is quite adverse; yet the amount of water required to attain equilibrium with some soils may be so large that practical use of the water is still feasible. The dynamics of the reactions between soils and the dissolved constituents of irrigation waters are therefore of importance. The present section is concerned with the amounts of irrigation waters which must be applied to obtain equilibrium between the waters and various depths of soils.

Thomas [12], Hiester and Vermeulen [9, 15] have developed equations for describing ion exchange and adsorption (including desorption) during the flow of solutions through columns where the equilibrium between dissolved and adsorbed constituents can be expressed by either mass-action type or Langmuir adsorption equations. The Thomas-Hiester-Vermeulen equations give the changes in the composition of dissolved and adsorbed constituents as functions of depth in the column and depth of solution applied. By using an approximate second-order rate equation to express the equilibrium for the exchange of sodium and calcium, Bower *et al.* [2] found that the Thomas-Hiester-Vermeulen equations described closely the saturation of soil columns, containing only adsorbed calcium initially, with sodium, and conversely, the saturation of columns, containing only adsorbed sodium initially, with calcium. Moreover, it was found that the equations described closely the equilibration of soil columns containing both adsorbed sodium and calcium with mixed solutions of these cations. In a subsequent study Brooks *et al.* [4] demonstrated under field conditions that the equations satisfactorily predict the changes in the compositions of the dissolved and adsorbed cations when soil is irrigated with a high-sodium water.

The exact solutions of the Thomas-Hiester-Vermeulen equations are complex as they contain functions which must be evaluated numerically. Moreover, use of the equations requires values for soil properties that must be obtained by direct determination. There are therefore

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[1] J. T. Hatcher, G. Y. Blair and C. A. Bower, unpublished data, U.S. Salinity Laboratory.

problems to be overcome in applying the equations to field situations. Progress is being made, however. For the important case where a high-sodium irrigation water is applied to a soil initially free of appreciable amounts of sodium, the depth of irrigation water required to equilibrate the water with the soil to any given depth may be estimated by the use of fig. 3, from the total cation concentration and the $c_{Na}/\sqrt{c_{Ca+Mg}}$ (mol./l.)$^{\frac{1}{2}}$ ratio of the irrigation water, and the cation exchange capacity and bulk density of the soil. In the preparation of fig. 3, the surface charge density of the soil is assumed to be 1.8×10^{-7} meq./cm.^{2}. Similar figures can be prepared using other values for surface charge density. To make estimations, the *F* value corresponding to the $c_{Na}/\sqrt{c_{Ca+Mg}}$ ratio and the total cation concentration of the irrigation water to be applied is read from the graph. This *F* value, when multiplied by the product of the cation exchange capacity in meq./100 gm., the bulk density in gm./cc., and the depth of soil in cm., gives an estimate of the depth of water in cm. which must pass through the depth of soil to equilibrate it with the water. For example, it is desired to estimate the amount of water having a $c_{Na}/\sqrt{c_{Ca+Mg}}$ (mol./l.)$^{\frac{1}{2}}$ ratio of 0.316 and a total cation concentration of 14 meq./l. which must pass through a soil having a cation exchange capacity of 10 meq./100 gm. and a bulk density of 1.5 in order to equilibrate the soil with the water to a depth of 20 cm. From fig. 3, the *F* value of the water is found to be 0.5. Hence, the amount of water in cm. required to attain equilibrium $= 0.5 \times 10 \times 1.5 \times 20 = 150$ cm.

The graph and formula shown in fig. 3 should be used with caution until it has received further experimental testing, as it is not yet known to what extent the removal of applied water by evapotranspiration affects its accuracy. In any case, the *F* value of a high-sodium irrigation water is a direct index of the amount of the water required to equilibrate soils with the water. The amounts of high-sodium waters required to attain equilibrium with initially sodium-free soil to a given depth increases directly with the *F* value of the water.

As it has been found that the equilibrium between dissolved and adsorbed boron in soils can be expressed by Langmuir's adsorption equation, the Thomas-Hiester-Vermeulen equations are, in turn, suitable for describing the dynamics of boron adsorption and desorption during the downward flow of waters in soil columns or profiles. Hatcher and Bower [8] tested the applicability of the equations in soil columns and obtained good agreement between theory and experimental results. Although, as in the cation exchange case, there remain problems in the application of the Thomas-Hiester-Vermeulen equations to the dynamics of boron adsorption in field situations, there are two immediately practical consequences of the equations which were experimentally verified by Hatcher and Bower. The first is that while the equilibrium adsorption of boron by soils increases as the boron concentration of the water increases, the depth of water required to attain equilibrium decreases as the boron concentration of the water increases. The second consequence is that elution of boron-saturated soil columns always requires leaching with a greater depth of boron-free water than that required to effect saturation.

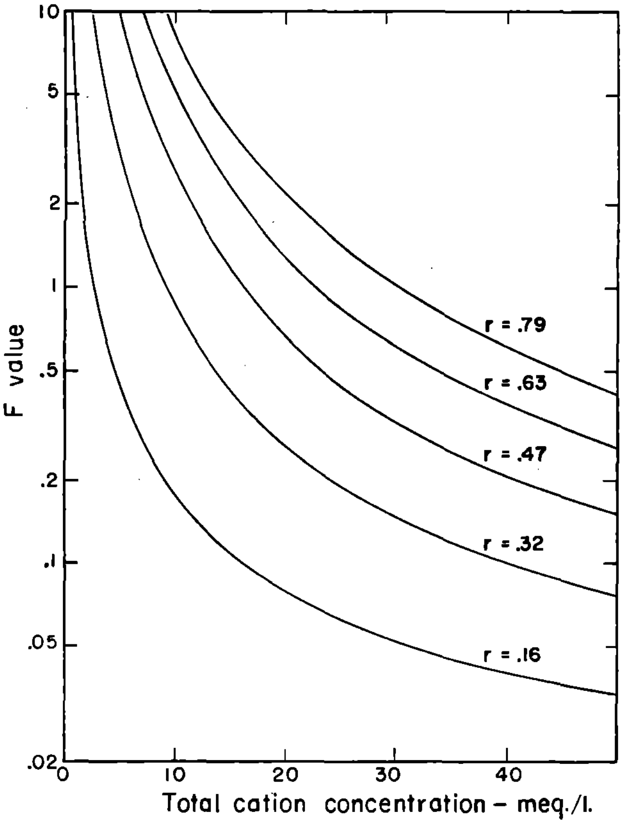

FIG. 3. Graph for estimating the amounts of high-sodium irrigation waters required to equilibrate the waters with soils initially free of adsorbed sodium. The symbol *r* denotes the $c_{Na}/\sqrt{c_{Ca+Mg}}$ (mol./l.)$^{\frac{1}{2}}$ ratio of the irrigation water. The amount of water in cm. required to equilibrate soil with water to a given depth = *F* value × exchange capacity in meq./100 gm. × bulk density in gm./cc. × soil depth in cm.

PRECIPITATION OF IRRIGATION-WATER CONSTITUENTS IN SOILS

Because the principal anions of irrigation waters are not adsorbed by soils of arid zones, the anionic composition of the soil solution, when the previous soil solution is displaced downward, is quite similar to that of the irrigation water. As the soil solution becomes more concentrated, however, owing to loss of water by evapotranspiration, bicarbonate and carbonate, if present, may precipitate as calcium carbonate with loss of carbon dioxide. This causes a corresponding increase in the proportions of chloride and sulphate, and a decrease in the proportion of calcium in the soil solution. Calcium sulphate is also a relatively insoluble salt, but it does not precipitate until the product of the calcium and sulphate ion activities exceeds about 6×10^{-5}. Unless the irrigation water contains an unusually high concentration of calcium and sulphate, or there is an appreciable accumulation of salts in the soil, precipitation of calcium sulphate does not occur.

In the preceding discussion of the effects of irrigation waters on the concentration of the soil solution and on the composition of the dissolved and adsorbed constituents in soils, it was assumed that no irreversible precipitation of constituents in the water occurred in the soil. Because the precipitation of calcium as calcium carbonate increases the proportion of sodium and decreases the total concentration of the soil solution, it is desirable to make allowances for the precipitation in predicting the effects of irrigation waters on soils. The logical procedure for doing this is to use an adjusted composition for the irrigation water which takes into account the anticipated precipitation of calcium carbonate in the soil. Eaton [6] and Doneen [5] assume that the precipitation is quantitative. Wilcox *et al.* [16] made 86 applications of synthetic irrigation waters containing various concentrations of calcium, sodium, bicarbonate and chloride to pots of soil in which grass was growing, and determined the percentage of the applied bicarbonate which precipitated as calcium carbonate in the soil. Sufficient drainage was allowed to take place from the pots, so that there was no appreciable accumulation of salts in the soil. It was found that the percentage of applied bicarbonate which precipitated as calcium carbonate in no case exceeded 54.

Langelier [11] has devised an index, termed the saturation index, for indicating the extent to which waters flowing through iron or galvanized pipes will precipitate or dissolve calcium carbonate. The saturation index is defined as the actual pH of a water ($p\mathrm{H}_a$) minus the pH (obtained by calculation) which the water will have when it is in equilibrium with calcium carbonate ($p\mathrm{H}_s$), viz.

$$\text{saturation index} = p\mathrm{H}_a - p\mathrm{H}_s \qquad (9)$$

Positive values of the index indicate that calcium carbonate will precipitate from the water, whereas negative values indicate that the water will dissolve calcium carbonate. The equation for calculating $p\mathrm{H}_s$, in its simplest form and applicable within the pH range 7.0 to 9.5, is:

$$p\mathrm{H}_s = (p\mathrm{K}_2' - p\mathrm{K}_s') + p\mathrm{Ca}^{++} + p\mathrm{Alk}. \qquad (10)$$

The last two terms are the negative logarithms of the molal and equivalent concentrations of calcium and titratable base, respectively, while $p\mathrm{K}_2'$ and $p\mathrm{K}_s'$ are the negative logarithms of the second dissociation constant for carbonic acid and the activity product of calcium carbonate, respectively, at the ionic strength and temperature of the water.

Wilcox[1] has calculated modified Langelier saturation indices for the waters containing bicarbonate described in reference [16]. The modification consists in using the pH of the soil in place of the actual pH of the water for calculating the index. The justification for the modification is that because irrigation waters are poorly buffered and soils are highly buffered the pH of the water becomes nearly equal to that of the soil upon contact with the latter. In fig. 4, the modified Langelier saturation indices for the irrigation waters are plotted against the percentages of the applied bicarbonate in the waters which precipitated as calcium carbonate in the soil. Also included in fig. 4 are data for six additional waters obtained in subsequent unpublished work[2] with the same soil. The data show that precipitation of calcium carbonate does not occur in the soil if the modified saturation index is negative, and that where the index is positive the percentage of the applied bicarbonate that precipitates is highly correlated with the value of the index. Further work may show that the composition of irrigation waters may be adjusted to account for the precipitation of calcium carbonate by calculation of the modified Langelier saturation index and the use of a relation such as shown in fig. 4.

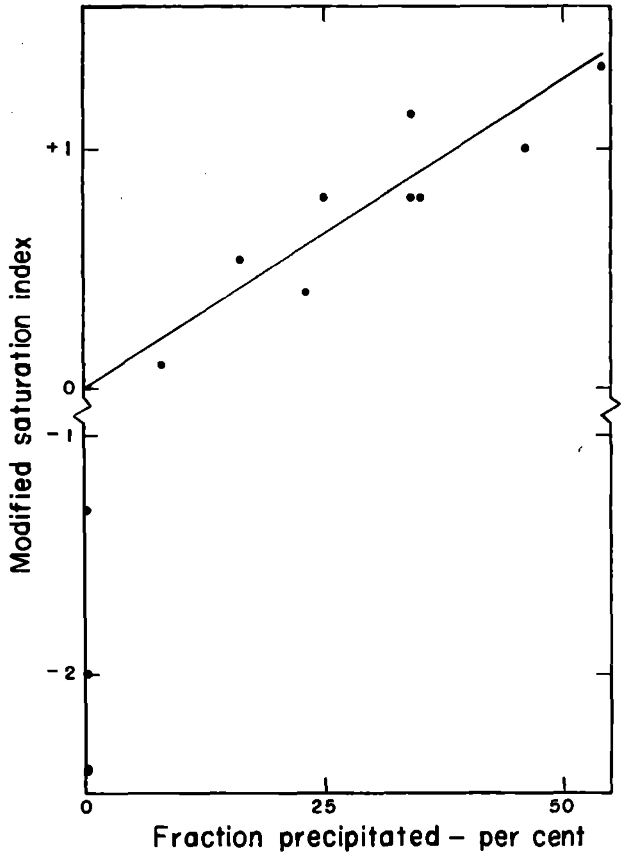

FIG. 4. Relation between the modified Langelier saturation index of irrigation waters and the fraction of bicarbonate in the water which precipitated as calcium carbonate in the soil.

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[1] L. V. Wilcox, unpublished work, U.S. Salinity Laboratory.

[2] L. V. Wilcox, G. Y. Blair and C. A. Bower, unpublished data, U.S. Salinity Laboratory.

RÉSUMÉ

Comment prédire les effets de l'eau d'irrigation sur le sol (C. A. Bower)

Les principaux effets directs de l'eau d'irrigation sur le sol peuvent se ranger en deux catégories: *a*) effets sur la teneur totale en sels de la solution du sol; *b*) effets sur la composition des minéraux dissous et adsorbés qui constituent le sol.

Le rapport entre la teneur totale en sels de l'eau d'irrigation et celle de la solution du sol dépend essentiellement, au bout d'un temps donné, du rapport entre le volume d'eau fourni au sol et celui qu'il a perdu par évapotranspiration. On obtient une équation qui, à partir de la teneur en sels de l'eau d'irrigation et du volume d'eau perdu par évapotranspiration, permet de calculer le volume d'eau à fournir au sol pour maintenir constante une certaine teneur en sels de l'eau de drainage.

Pour prédire les effets de l'eau d'irrigation sur la composition des minéraux dissous et adsorbés qui constituent le sol, deux éléments d'information sont indispensables: *a*) la composition approximative des minéraux adsorbés lorsque la teneur en sels du sol et celle de l'eau sont en équilibre; *b*) le volume d'eau qui doit être fourni afin de réaliser cet équilibre jusqu'à une profondeur donnée pour divers constituants de l'eau. Le pourcentage d'équilibre des cations adsorbés peut être évalué à partir de la composition de l'eau au moyen de l'équation d'Eriksson (équilibres d'échange de cations), et le rapport entre le bore adsorbé et la teneur de l'eau en bore est donné approximativement par l'équation d'adsorption de Langmuir. Enfin, la théorie de Thomas, Hiester et Vermeulen permet de calculer les volumes d'eau nécessaires pour réaliser l'équilibre de la solution du sol jusqu'à diverses profondeurs pour divers constituants de l'eau.

DISCUSSION

G. **Aubert**. (1) J'ai été extrêmement intéressé par le remarquable exposé du D^r Bower. En fait, une difficulté à appliquer ce "modèle" est due à ce que l'eau qui pratiquement pénètre dans le sol est plus concentrée — par évaporation — que l'eau d'irrigation apportée, surtout si le sol est peu perméable. Aussi ai-je été très frappé dans certains graphiques, en particulier celui de prévision de la constitution du complexe absorbant du sol, par la concordance entre les résultats obtenus et les résultats calculés.

Les sols utilisés dans ces expériences étaient-ils particulièrement perméables?

(2) Les sols et les eaux utilisés par le D^r Bower étaient-ils parfois très riches en Mg par rapport à leur teneur en Ca et même en Na? En ce cas, l'action de Mg a-t-elle été toujours analogue à celle de Ca?

C. A. **Bower**. (1) In relating the $Na/\sqrt{Ca + Mg}$ ratio of irrigation waters to the exchangeable sodium percentage of soils in the field, sites where the permeability was very low were avoided.

(2) Irrigation waters were studied in which the magnesium concentration was at least equal to that of calcium. In our work on cation exchange we find that magnesium behaves very much like calcium and that we can combine the two cations.

A. R. **Kamaliddin**. In connexion with the experimental study of boron equilibria, is it assumed that no boron is removed by precipitation, or is this measured, and if so, how is the measurement carried out?

C. A. **Bower**. The fact that Langmuir's equation describes the adsorption reasonably well indicates that there is no significant preciptation of boron compounds. Adsorption is taken to be the difference between the amount applied and that remaining in solution. Adsorbed boron can also be removed by leaching with boron-free water.

M. M. **El-Gabaly**. Does the nature of the clay mineral of the soil have any effect on the equations suggested?

C. A. **Bower**. It does to the extent that illites usually have a high surface charge density and montmorillonites characteristically have a low surface charge density. If significant concentrations of potassium are involved specific adsorption (fixation) effects occur.

I. **Zafar**. When selecting samples of irrigation water to determine its effect on soils, were its physical properties such as silt content, temperature, etc., taken into account in any way, especially in relation to the time dimension affecting the duration of any reaction?

C. A. **Bower**. Sampling sites were selected where it was known that the soil had good drainage and reasonable permeability, and that irrigation had been performed for a considerable period of time with water of nearly uniform composition. To enhance the probability that the soil sample was in essential equilibrium with the water only the surface layer (0–6 in.) was sampled.

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THE SYSTEM OF SCIENTIFIC INVESTIGATION IN PROJECTS FOR THE IRRIGATION AND RECLAMATION OF SALINE SOILS

by

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The system of scientific investigation for planning irrigation and reclamation of saline soils consists of engineering, geological, geomorphological, hydrogeological and soil-reclaiming investigations.

We have adopted in the U.S.S.R. a system in two stages: a programme project, and a working project (work drawings). But in the case of major projects a provisional "irrigation scheme" is usually planned on the basis of available information and, if this is insufficient, supplementary investigations are carried out. Planning of the irrigation of smaller areas, up to 500 hectares, is carried out on the basis of available data and of direct study of the site by various specialists.

The project programme solves all hydrotechnical and reclamation problems as such. Therefore detailed investigation data must be collected at this stage of the project.

The varying scale of these investigations depends on the complexity of natural conditions and on the size of the territory studied. Engineering and geological investigations are carried out on scales of from 1: 10,000 to 1: 50,000; hydrogeological investigations, from 1: 25,000 to 1: 50,000; soil reclamation, on scales of 1: 10,000 (on areas of 500 to 2,500 hectares), 1: 25,000 and 1: 50,000 (on areas over 10,000 hectares). Geomorphological investigations are relatively seldom carried out by independent units; usually they are combined with hydrogeological and soil-reclaiming investigations.

Before any investigation is carried out it is necessary to study the existing literature concerning (a) the bioclimatic conditions of the territory to be cultivated, (b) its hydrology, and (c) its geological and geomorphological structure and also its soil-covering. This must be done in order to establish the principal natural particularities of the territory to be irrigated, and also to establish the programme of forthcoming investigations.

The engineering and geological investigations must bring out the characteristics of the geological structure of the sites of the future hydrotechnical constructions (water gates, canal routes and water collectors, etc.), and the conditions necessary for maintaining their stability under operational conditions. The geomorphological investigations aim at elucidating the particularities of the geomorphological structure of the whole territory to be developed and the character of its relief. The aim of hydrogeological investigations is to study the origin, depth of occurrence, chemism, direction and rapidity of movement, and regime of the ground-water, and also to study the lithology of the ground and its filtration properties. Soil-reclaiming investigations establish the genetic and reclamation characteristics of the soils and the soil-covering of the territory under study. All these investigations are accompanied by the preparation of corresponding maps, drawn according to the aforementioned scales.

The following main questions arise in soil-reclaiming investigations: (a) the characteristics of the soil-cover, particularly in relation to salinization; (b) the forecasting of the positive and the negative effects of irrigation upon the reclamation state of the territory studied; (c) the basis of reclamation measures for improving soils with unfavourable properties and for preventing and eliminating possible processes of secondary salinization and secondary swamping; and (d) the ascertaining of a rational control of agricultural development (for reclamation purposes).

These tasks may be carried out with success only on the basis of an investigation that covers the whole system: soil, subsoil and ground-water. Thus, the soil reclamation investigations naturally cover deep profiles, and embrace the strata down to the depth at which the ground-water occurs, or in other words down to 4–5 m., when the ground-water is at some depth. This distinguishes them from the ordinary soil investigations, dealing only with the soil profile. The study of soils on lands analogous to the examined territory and of their transformation under irrigation is an essential condition for full-value reclamation forecasting.

Soil-reclamation investigations are carried out in three stages: fieldwork, analytical work in the laboratory and, finally, computation and interpretation. The most important stage is the fieldwork, during which the land is surveyed and a detailed study of the soils, the mother-rocks and the ground-water is carried out by recognized methods. During the second stage the requisite analyses of laboratory samples of soils, subsoil layers and ground-waters are performed; in the third stage the data obtained is generalized and checked with the results of investigations conducted by geomorphologists, hydrogeologists, or other specialists, and also with data to be found in the relevant literature.

The method of field soil-reclamation investigations is a comparative soil-geographical one, first created by V. V. Dokutchaeff and further developed in the works of N. M. Sibirtseff, S. S. Neustrueff, B. B. Polynoff, L. I. Prassoloff, N. A. Dimo and others. Much work has been done on the methods of soil-reclamation investigations on saline soils by scientists outside the U.S.S.R.: Hilgardt, Kelli, Zigmont and others.

The soil-reclamation investigations must be based on careful checking of geomorphological and hydrogeological conditions. In many cases the pedologists complement and develop the data obtained by the geomorphologists and hydrogeologists. It is essential, therefore, that the soil-reclamation geomorphological and hydrogeological investigations be effectuated in a closely co-ordinated manner. Only in this way can solutions be found to such basic questions as the following: (a) what are the genetic relations between the territory studied and the adjoining area (for instance, is this a region from which aqueous and salt masses are carried out, or a transitional one, or one in which accumulation takes place); (b) what are the degree and character of natural drainage in this territory; (c) on what parts of this territory can one expect desalinization, secondary salinization and secondary swamping to occur under irrigation.

In distinguishing various soils on a field soil map, one applies existing genetic classifications. It is necessary to try to determine first, in the field, what is the relation of a given genetic soil group to the possible consequences of irrigation (e.g. secondary salinization and secondary swamping). This assessment is based on an analysis of the following factors: (a) the conditions in which the soils occur; (b) the degree and character of salinization, and the nature of the hydrogeology of the soils; (c) the changes expected in the water-salt regime of the territory.

Attention in soil-reclamation investigations must be paid mainly to the reasons for the particular degree and sort of soil salinization obtained. The origins of salinization in soils may be very different. In some cases salinization is related to complex geochemical features of the present time, or of a past epoch. In many places it is residual, inherited from former stages of soil-formation; or it is a contemporary process, caused by the proximity of saline beds in mineralized rocks and in the ground-water. Finally the salinization of grounds may be secondary by origin and caused by bad irrigation.

Among present and secondary salinizations one must distinguish seasonal (intermittent) and steady (progressive) salinization; differences in the character of the salt accumulations are apparent, depending on whether the territory belongs to this or that salt province.

The degree of salinization of soil depends, according to the majority of investigators, on the depth of the salt horizons (i.e. over 0.25 per cent of salts in the water extract) in the soil profile, and on the quantity of salts contained in it. The following soils are distinguished: non-saline (the salt horizon is absent down to 150–200 cm.); deeply saline (the salt horizon is at 100–150 cm.), deeply alkalinized (at 70–80 cm.), alkalinized (at 30–50 cm.); alkaline (at 5–30 cm.); salt marshes or solonchaks (deeply saline from the surface and containing over 1–1.2 per cent of salts). There are also other varieties of salinization; for instance, cases of strongly expressed superficial salinization are often observed on low terraces of river valleys (superficial alkaline soils and superficial salt marshes), along with insignificant salt contents in deep beds. In regions of secondary salinization broadly developed soils with a two-layer salinization are found; there are two salt horizons in their profile—one at a certain depth, the other nearer the surface.

Depending on the salt content in the saliferous horizon, one distinguishes the following types of soil: slightly saline (with less than 0.5 per cent of salt), moderately saline (0.5–0.7 per cent), highly saline (over 0.7 per cent of salts), deeply saline, deeply alkalinized, alkalinized, and alkaline.

The types of salt accumulation in soils vary greatly. The most frequent are the following: bicarbonate, sodium-bicarbonate, sodium-sulphate, chloride, sulphato-chloride, chlorido-sulphate, sulphate and sulphate gypsum.

The degree and type of soil salinization are first determined in the field on the basis of morphological indications, the character of the vegetation, qualitative reactions and so forth. They are then established definitely by means of chemical analyses of water and acid extracts (0.25 norm. HCl), which elucidate the quantity and composition of the water-soluble salts and gypsum. The analyses are carried out for basic sections at the following depths: down to 1.5–2.0 m., and from 1.5–2.0 m. down to 4–5 m. The analysis of the first section is necessary in order to establish the quantity and composition of the salt reserves in the root-zone of soils; the analysis of second section performs the same functions for that part of the strata that must be demineralized in order to attain a stable reclamation state. Besides such full analyses others are performed with a reduced number of components, and are usually carried out by simplified methods. They are necessary in order to establish the variability of salinization, depending on different conditions.

In studying saline soils it is essential to determine the values of the critical depth and of the critical mineralization of ground-waters. This is done by analysing the nature of relations existing between the structure of the salt and humidity profiles of soils, and the depth and the mineralization of ground-waters. Elucidation of the problem of the influence of the various structures and the composition of subsoil layers upon the character of salinization is also of great importance for reclamation since it makes it possible to assess the degree of natural drainability of the soils.

In saline regions we often find salt marshes and alkaline soils. Their presence in the soil-cover of the area makes it necessary to elucidate: (a) the conditions of their formation; (b) the extent and character of alkaline phenomena, and the methods for combatting them; (c) the methods to be adopted against alkalinity that may occur during future irrigation; (d) the reclamation measures necessary for the desalinization of soils. Alkalinity may be residual or contemporary, slight or high, superficial or attached to the medium part of the profile. Usually it is combined with the salinization of the soil profile (under alkaline salinization). We know of cases of potential (concealed) alkalinity; these have been observed mainly in highly saline soils of definite chemical composition.

One of the necessary stages of soil-reclamation investigations is the study of the physics of water in soils and subsoil layers. These investigations aim at obtaining various physical constants for calculating the quantities of water required for drainage, irrigation, and leaching. Such values include data on the density of undisturbed samples, porosity, field moisture capacity (minimum), withering humidity, speed of imbibition, water and salt yield, coefficients of vertical and horizontal filtration, etc. Such investigations also aim at characterizing the capillary properties of soils and subsoils, and the tendency of the latter to disappear. Owing to their specific character, the investigations are carried out by special groups of pedologists and physicists, working in specially chosen areas of typical soils.

Soil-reclamation investigations of this kind are only carried out one at a time, and from time to time. Consequently they do not give the time course of the variations of salinity. Of great importance for the soil-reclamation evaluation of a territory are the stationary and semi-stationary studies on the water-salt balance, the water-salt regime, the leaching of saline soils, and the development of soils with unfavourable properties (alkaline soils —solontsy, *takyrs*, etc.). However, such investigations are not usually included in the prospecting programme for irrigation system projects. As a rule, they are carried out as special tasks, mainly during the agricultural development of the irrigated territory. As an example, let us mention the experimental reclamation investigations in the Golodnaya Steppe or "famished steppe" (Uzbekistan); in the valley of the river Amu-Darya (Turkmenistan); in the valley of the river Vakhsh (Tadjikistan), in the Mugansk Steppe (Azerbaijan). The theoretical importance of these investigations is very great. Hence application of their results is compulsory for any new soil-reclamation investigation, but it is necessary to check carefully the special natural characteristics of the locality.

As a result of soil-reclamation investigations a soil-reclamation map is drawn and accompanied by an explanatory note. This map shows the types, sub-types, species and varieties of soils and gives more than usually detailed indications as to the degree and character of salinization. The map also indicates the geomorphological and hydrogeological conditions (depth of groundwater, its mineralization, the character of subsoils) for the different soils. This is the main difference between such a map and the usual soil map.

The soil-reclamation investigations are concluded by dividing the territory into soil-reclamation districts. The division is based on a forecast of possible variations in the hydrogeological conditions of the soil, when under irrigation.

The natural conditions favouring or hampering such variations (natural drainage or its insufficiency, good or insufficient superficial run-offs, natural salinization, etc.) are elucidated at the same time.

Depending on the results of the forecast, not only are the soil-reclamation districts established, but areas are also defined on the basis of the priority of irrigational measures, which in their turn imply certain steps in the fields of: (a) hydrotechnology (artificial drainage, construction of embankments); (b) water-economy (combatting filtration in the network, the water consumption regime, etc.); (c) agrotechnology (planning, prophylactic watering, the character of the watering regime of the crop rotation, etc.); (d) improvement of soils whose primary development is difficult (alkaline soils and salt marshes, alkalinized soils, *takyrs*, badly swamped areas).

Finally, questions are listed for subsequent study, during the work planning stage and as subjects for special stationary or semi-stationary investigations aimed at furthering the agricultural development of the territory.

RÉSUMÉ

Études scientifiques nécessaires à l'établissement des projets d'irrigation et de récupération des sols salins (A. N. Rozanoff)

La présente communication porte sur les caractéristiques des recherches visant à la récupération des terres.

Les principaux problèmes sur lesquels doivent porter les recherches sont les suivants: *a*) caractéristiques de la couverture végétale, notamment dans ses rapports avec la salinisation; *b*) prévision des effets, positifs ou négatifs, de l'irrigation sur la récupération du territoire considéré; *c*) bien-fondé des mesures visant à améliorer les sols, et des mesures destinées à empêcher la salinisation et la saturation hydrique secondaires. Ces problèmes n'ont de chances d'être résolus que moyennant des recherches globales menées d'un point de vue génétique, sur les sols, les sous-sols et les eaux souterraines.

Lorsqu'on étudie les sols par les méthodes classiques, tout le travail doit être fait du point de vue de la récupération. L'essentiel, dans une étude de ce genre, est de déterminer les facteurs naturels et économiques de la salinisation, de la saturation en eau et de l'alcalinisation existantes. Cette étude est poursuivie jusqu'au niveau de la nappe phréatique ou, si ce niveau se trouve à une trop grande profondeur, jusqu'à 4 ou 5 mètres.

Les recherches visant à la récupération des terres doivent obligatoirement comprendre l'étude des propriétés hydrophysiques des sols et des sous-sols. Cette étude a pour but d'établir les diverses constantes hydrophysiques nécessaires au calcul de normes qui serviront pour le drainage, les arrosages et l'irrigation par ruissellement.

Toutes ces recherches sur la récupération des sols permettent d'établir une carte de mise en valeur, accompagnée d'une note correspondante. Sur cette carte sont portés les types, sous-types, espèces et variétés de sols, ainsi que les conditions géomorphologiques et hydrogéologiques dans lesquelles ils se développent. C'est ce qui différencie ces cartes des cartes pédologiques habituelles.

La dernière phase des recherches consiste à diviser en secteurs les sols à récupérer. Cette division est fondée sur les modifications que l'irrigation pourra faire subir à la couverture végétale. D'après les prévisions qu'on établit alors, on distingue diverses zones, suivant ce qu'on attend d'elles et l'ordre dans lequel elles seront irriguées, en indiquant les diverses mesures à prendre pour la récupération.

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MOVEMENT OF EASILY SOLUBLE SALTS IN SOLONCHAK SOILS UNDER LEACHING

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This report gives a review of field experiments carried out in order to study the following questions: (a) displacement of salt solutions from solonchaks, as a result of leaching under various hydrogeological conditions (ground-water near the surface and deep below); (b) dependence of the degree of salt displacement upon the quantity of water applied.

In the development of saline soils, particularly of virgin soils, cases are observed: (a) in which soils are saline, but ground-water occurs sufficiently deep (10–30 m.); (b) in which salinization is connected with a high water table of slightly saline ground-water.

The first case occurs in areas in which salinization was caused by a higher water table in the past. Later, owing to this or to other causes, the level of the ground-water fell, but soil salinization remained. Such areas include ancient deltas, ancient terraces (benches) and also certain parts of dry deltas on alluvial and diluvial cones of sedimentation. The second case is to be observed in recent (younger) parts of deltas and on river flood-plains.

Our investigations aim at showing how the salts are carried out of the soil profile during leaching under dry ground conditions (with a low water table), and how the salts are transferred, with a high water table, in conditions of capillary moistening of soils.

There is a certain amount of data on this problem in the literature. According to V. R. Volobueff (1948), there are direct, though very scarce, references to the relation between the intensity of leaching and the depth of ground-water. A slackening and hindering influence of the capillary rehumidification upon the leaching of salts during washings was noted.[1]

All available data on this question underline the exclusive influence of the state of soil moisture and of the depth at which ground-water occurs upon the intensity of leaching.

Investigations on the leaching of saline soils with a low water table may include the experiments carried out on the Kizyl-Arvat Station and on the Tashaouz Experimental Station in the region of Kunia-Urguench and, for soils with a high water table, the experiments carried out at the Kara-Kalpak Experimental Station.

The Kizyl-Arvat Station is situated in a plain at the foot of the Kopetdag Mountain range. This plain was formed by ancient alluvial and diluvial cones of sedimentation, and by a diluvial shift. It is formed of stratified sediments of extremely multi-coloured composition. The depth of the ground-water is 30–35 m.

The soil-covering of the plain is represented by vast open solonchak massifs, alternating with *takyr*-like crust, and fluffy solonchaks.

The Tashaouz Experimental Station is situated to the north-east of the town of Kunya-Urguench, on the left bank of the Amu-Darya, on desert land of ancient irrigation with a great number of solonchaks. These massifs were developed in ancient times, but were later, for various reasons, excluded from agriculture. Salinization of these soils was caused by the high water table of mineralized ground-waters in the period when the region was intensely developed and was in reality a living delta. During the subsequent lowering of the ground-water level in arid conditions, not even the slightest desalinization took place. (The level of the ground-water under non-irrigated soils fell to 6–8 m. and 12–15 m.)

The Kara-Kalpak Experimental Station is situated in the centre of the Chimbay oasis, in the most intensely irrigated part of the contemporary delta of the Amu-Darya. Ground-water occurs at a depth of 0.5–3 m. In lowlands, where the water table is high, the soil covering is represented by meadow, and crust or fluffy solonchaks. Solonchaks studied in these three regions are characterized by the following: down to a depth of 50–80 cm. the soils are formed by slightly permeable, heavy clays and clayey loams; lower than 50–80 cm. there are light sandy loams with good permeability. Owing to the heavy physical composition of the upper layers, the soils possess, on the whole, a lower permeability. The upper horizons have

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[1] Similar opinions were ventured by many other investigators: I. I. Lopato (1932), S. I. Sushko (1932), V. V. Fedoroff (1934), I. F. Muzychuk (1936), V. S. Malyguin (1939), I. S. Rabocheff (1951).

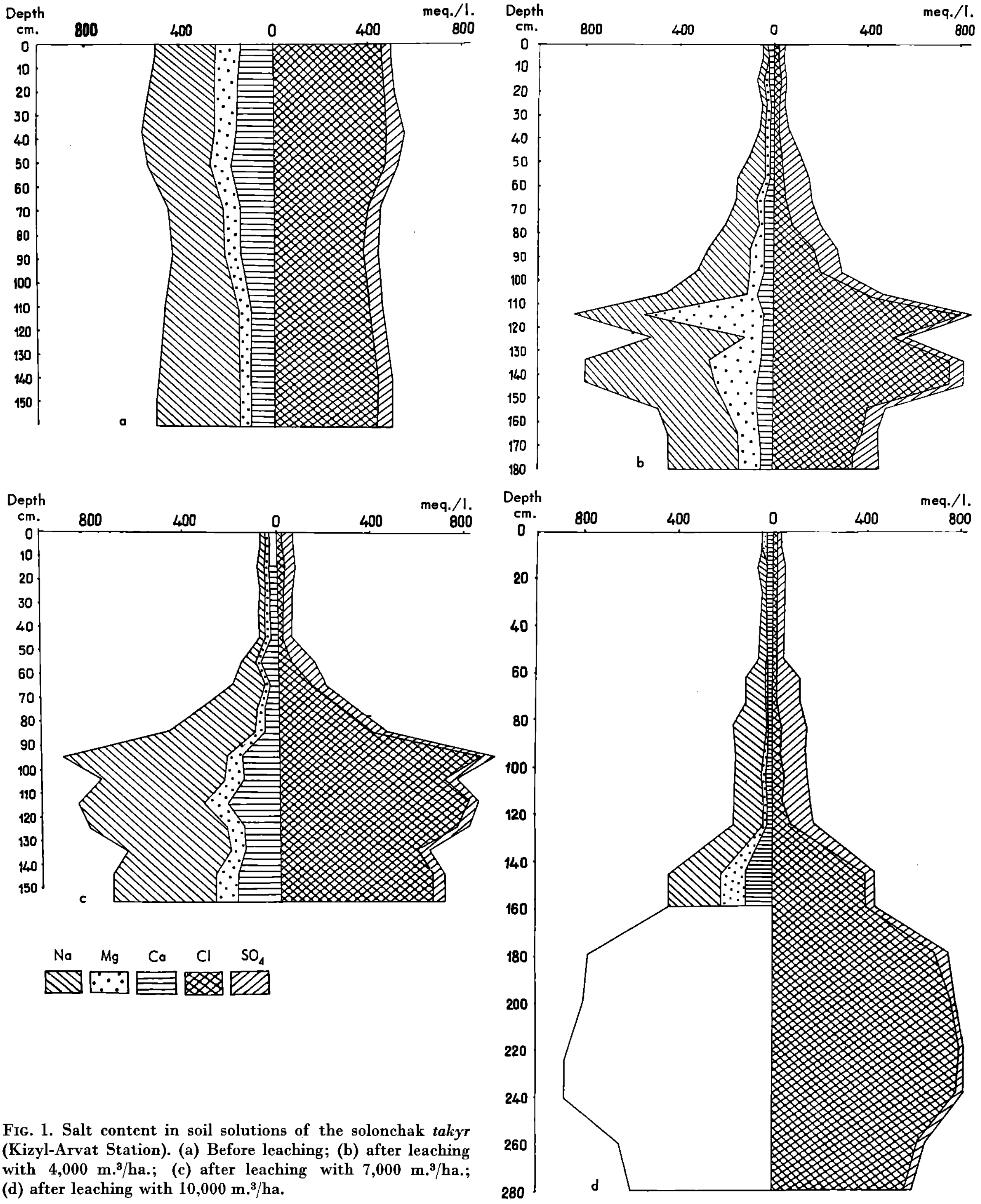

FIG. 1. Salt content in soil solutions of the solonchak *takyr* (Kizyl-Arvat Station). (a) Before leaching; (b) after leaching with 4,000 m.^{3}/ha.; (c) after leaching with 7,000 m.^{3}/ha.; (d) after leaching with 10,000 m.^{3}/ha.

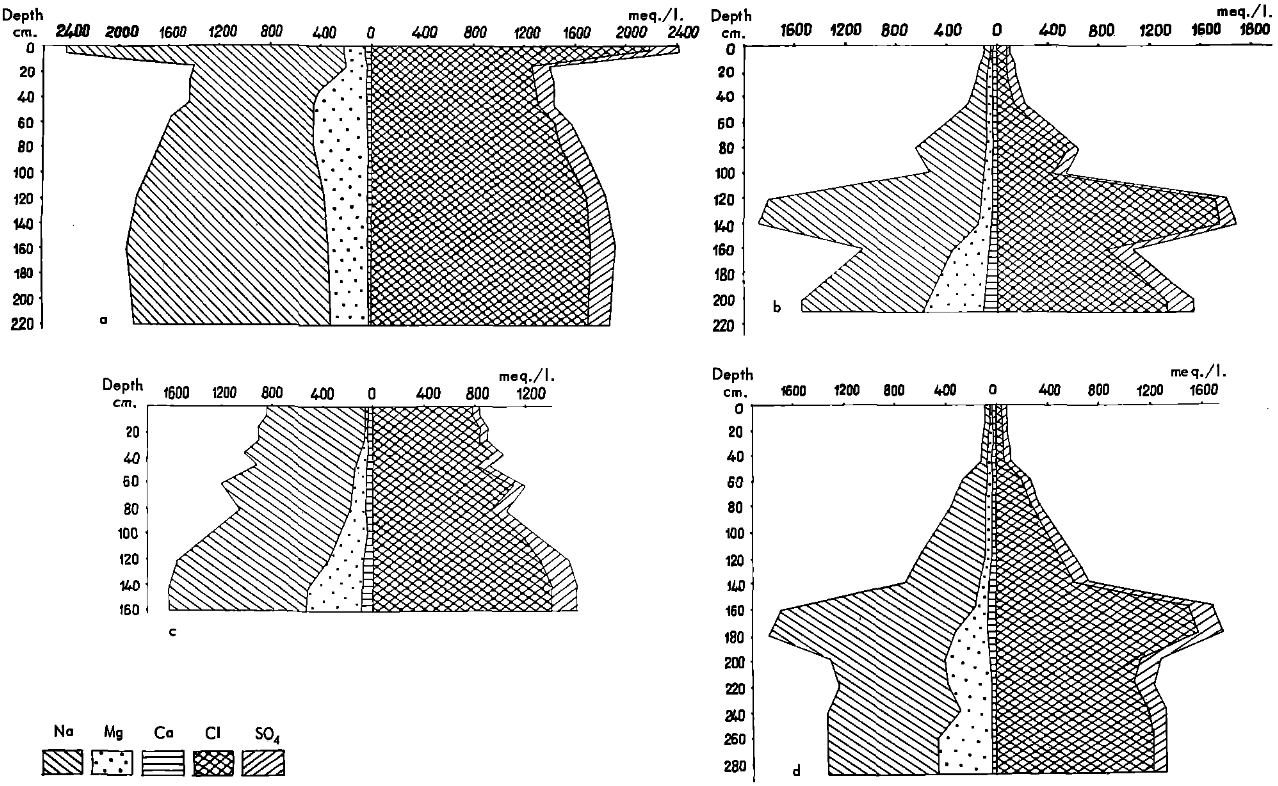

FIG. 2. Salt content in soil solutions of crust solonchak (Tashaouz Experimental Station). (a) Before leaching; (b) after leaching with 4,000 m.^{3}/ha.; (c) after leaching with 7,000 m.^{3}/ha.; (d) after leaching with 10,000 m.^{3}/ha.

a dense structure; the average density of an undisturbed sample is 1.5. The limit of field water capacity in the upper soil layers is 24–26 per cent and in the lower ones 21–22 per cent.

The humidity deficit was calculated for each of the solonchaks that had been washed out. This deficit is the difference between field capacity and actual moisture content at the moment leaching begins.

Calculations were made for the 1 m. layer. From the data obtained, it was clear that in the 1 m. layer the humidity deficit was higher, the lower the water table: in the solonchak *takyr* on the Kizyl-Arvat Station the humidity deficit before leaching was 1,966 m.^{3}/ha.; on the solonchak of the Tashaouz Experimental Station this deficit was about 1,000 m.^{3}/ha., and in the crust solonchak at the Kara-Kalpak Station about 400 m.^{3}/ha.

On the Kizyl-Arvat Station experiments were carried out on leaching of solonchak *takyrs*. The following water quantities were applied: 4,000, 7,000 and 10,000 m.^{3}/ha.

When the salinization of a given soil was a chloride one, check was kept on the chloride content as the means of measuring the effectiveness of the leaching. Before the leaching, the Cl′ content of a hydrous extract of the entire soil profile was SO_4''—0.6 per cent. Field water capacity for the entire profile was from 7–12 per cent.

When 4,000 m.^{3}/ha. of water was applied to a depth of 0–50 cm., the Cl′ content diminished to 0.02 per cent; below 50 cm. it increased to 0.05–0.8 per cent. With a water quantity of 7,000 m.^{3}/ha. the Cl′ content at a depth of 0–50 cm. became 0.015 per cent; in the 50–70 cm. layer it was 0.03 per cent; below 70 cm. a sharp increase was observed—0.06–0.5 per cent.

With a leaching by 10,000 m.^{3}/ha. the Cl′ content at a depth of 80 cm. was already 0.009–0.016 per cent; in the 80–100 cm. layer it was 0.023–0.026 per cent. Below the first metre the Cl′ content increased to 0.05 per cent.

A similar situation was observed with regard to the soil solutions. Before leaching the Cl′ content in the solution of the entire solonchak profile was 14–17 gm./l. With 4,000 m.^{3}/ha. of water the Cl′ content in the soil solution of the 0–50 cm. layer became 1.4 gm./l.; the salts were carried down to a depth of 110–120 cm. With 10,000 m.^{3}/ha. of water, the above-mentioned desalinization of the solution was observed down to a depth of 1 m., and the highest salt content was to be found deeper than 1.5 m. (fig. 1).

Salinization of the solonchak crust on the Tashaouz Station is higher than on the solonchak *takyr* of the Kizyl-Arvat Station. Because of this, larger quantities of water were introduced: 4,000, 10,000 and 14,000 m.^{3}/ha.

On examining the moisture profile, it may be seen that field humidity (capillary moisture suspended in the upper soil layers) reaches 15–19 per cent, and the capillary fringe begins at 3.7 m.

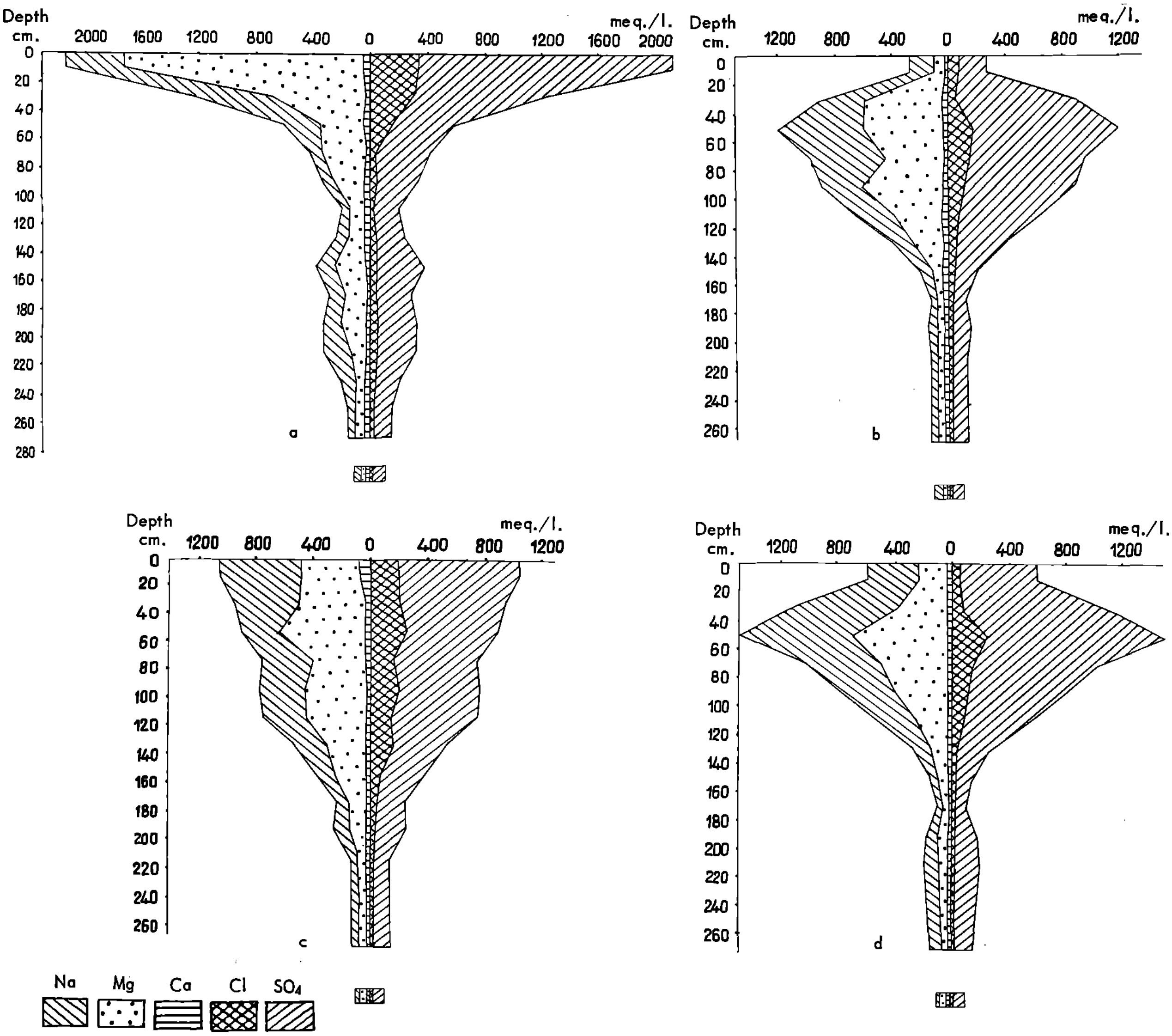

FIG. 3. Salt content in soil of crust solonchak (Kara-Kalpak Experimental Station). (a) Before leaching; (b) after leaching with 4,000 m.^{3}/ha.; (c) after leaching with 6,000 m.^{3}/ha.; (d) after leaching with 8,000 m.^{3}/ha.

Before leaching, the dry residue of the soil solution in the 0–10 cm. layer was 3.1 per cent; lower, its value changed from 2 to 1.5 per cent. The Cl′ content in the solonchak profile was equal to 1.1–0.60 per cent.

Here leaching with 4,000 m.^{3}/ha. of water had almost no effect; the salt content diminished only in the 0–20 cm. layer, dry residue in 0–10 cm. layer fell from 3 per cent to 1 per cent and in the 10–20 cm. layer from 2 per cent to 1.5 per cent. The quantity of Cl′ in the 0–10 cm. layer fell from 1 per cent to 0.4 per cent, and in the 10–20 cm. layer from 0.75 per cent to 0.5 per cent.

Leaching with 10,000 and 14,000 m.^{3}/ha. of water had a greater effect. In the first case, it lowered the salt content in the first half-metre from 3.2 per cent to 0.7–0.4 per cent and the Cl′ content from 1–0.7 per cent to 0.06–0.04 per cent. In the second case, analogous desalinization developed at a depth of 70 cm.

Before leaching, the concentration of the solution in the 0–10 cm. layer was 142 gm./l.; the Cl′ content in this layer, 77 gm./l. Lower, down to the second metre, salt concentration equalled 100–110 gm./l.; Cl′ content was 60–62 gm./l.

Under the 4,000 m.^{3}/ha. leaching the concentration of the soil solution in the 0–10 cm. layer fell from 142 gm./l. to 50 gm./l.; the Cl′ content diminished from 77 gm./l. to 28 gm./l. Further down in the soil profile the concentration of the solution decreased; this, however, was not due to the salts being carried out, but to greater soil humidity (20–23 per cent, against 15–19 per cent).

Under the 10,000 m.^{3}/ha. leaching the concentration of the soil solution in the 0–20 cm. layer fell from 142 gm./l. to 5.6 gm./l., and in the 20–50 cm. layer from 80–82 gm./l. to 8–13 gm./l. The Cl′ content in the 0–50 cm. layer diminished from 77–46 gm./l. to 2.5–40 gm./l., and in the 50–70 cm. layer from 47 gm./l. to 10 gm./l.

Under a 14,000 m.^{3}/ha. leaching the same picture of desalinization developed in the upper part of the soil profile to a depth of 90 cm., and the salts were carried down to a depth of 150–190 cm. (fig. 2).

On the Kara-Kalpak Experimental Station investigations were carried out on the crust solonchak of the sulphate salinization type.

Ground-water occurs at a depth of 3 m. Salt content in ground-water was 6.2 gm./l.; SO_4'' content was 3.6 gm./l.; Na content was 1.3 gm./l.

The salt profile of the crust solonchak, before leaching, had a strongly expressed solonchak appearance (fig. 3). The quantity of easily soluble salts in the 0–20 cm. layer attained 4.7 per cent; the SO_4'' content was about 3 per cent, and that of Cl′—0.38 per cent. Lower down the soil profile, a gradual and smooth decrease in these percentages was observable.

The concentration of the soil solution in the surface layer attained very high values, such as 130 gm./l.; the SO_4'' content was 86.2 gm./l.; the Cl′ content equalled 11.9 gm./l. In the lower soil layers the salt concentration in soil solutions approached that of the ground-water (6–7 gm./l.).

The following quantities of water were applied: 40,000 m.^{3}/ha., 6,000 m.^{3}/ha. and 8,000 m.^{3}/ha.[1]

From a general outline of the influence of watering at the Kara-Kalpak Station it may be seen, first of all, that in these conditions the effect of leaching was quite different from that obtained in the two preceding cases: slight desalinization occurred only in the most superficial soil layers—the 0–20 cm. and the 0–40 cm. ones. Migration of salts through the profile was observed down to 80 cm. or 100 cm. Thus, when 4,000 m.^{3}/ha. leachings were applied the SO_4'' content in the 0–20 cm. layer decreased from 3 per cent to 1.08 per cent; in the 20–40 cm. layer it hardly changed, and in the 40–80 cm. layer the SO_4'' content increased slightly, from 1.1–0.8 per cent to 1.5–1.2 per cent.

When 6,000 and 8,000 m.^{3}/ha. leachings were applied, the SO_4'' content in the 0–40 cm. layer decreased slightly, while salts migrated into the 60–100 cm. layer. (The behaviour of chlorides was analogous to that of sulphates.)

As may be seen from the above figures, which indicate the movement of the salts in the soil solutions, active migration occurred only in the 1 m. layer. In the lower layers no changes took place as a result of the influence of watering.

On the three land plots where experiments were carried out salt reserves were calculated in tons per hectare on half-metre soil-layers (Tables 1 and 2). Reserves were also calculated for a 1.5 m. layer before and after leaching. Initial salt content (Cl′ and SO_4'') were taken as 100 per cent.

If, on the basis of this data, the results of leachings on solonchak soil on the Kizyl-Arvat Station are compared with those carried out on the Tashaouz Experimental Station, it may be observed that in the first case there is a marked desalinization of the 1 m. layer, and that the salts are carried deeper in the soil, when 10,000 m.^{3}/ha. of water are applied in the Kizyl-Arvat Station at a depth of 100–150 cm., salts are still carried away (reserves

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[1] Here the quantities of water were diminished owing to the high water table.

Table 1. Influence of quantities of water on desalinization of solonchak soils at different water tables

Place of investigation and soil	Soil depth in cm.	Content before leaching (t./ha.)		Percentage of initial quantity remaining after leaching with 4,000 m.^{3}/ha.		7,000 m.^{3}/ha.		10,000 m.^{3}/ha.		14,000 m.^{3}/ha.	
		Cl′	SO_4''	Cl′	SO_4''	Cl′	SO_4''	Cl′	SO_4''	Cl′	SO_4''
Kizyl-Arvat Station (solonchak *takyr*)[1]	0–50	27.4	—	4.6	—	4.1	—	3.2	—	—	—
	50–100	38.4	—	51.6	—	16.2	—	3.6	—	—	—
	0–100	65.8	—	32.1	—	11.2	—	3.5	—	—	—
	100–150	23.9	—	234.8	—	264.1	—	57.7	—	—	—
	150–200	22.5	—	102.6	—	135.0	—	353.8	—	—	—
Salts washed out of 0–100 cm. layer, as percentage of initial quantity											
	0–100	—	—	67.9	—	88.8	—	96.5	—	—	—
	0–50	63.0	42.1	71.7	71.3	—	—	4.8	37.5	4.6	34.4
	50–100	54.6	20.9	110.2	163.0	—	—	32.2	84.2	18.3	73.7
	0–100	117.6	63.0	88.4	99.4	—	—	18.5	53.0	11.0	47.5
	100–150	68.6	27.5	—	—	—	—	171.9	140.7	76.7	102.1
Salts washed out of 0–100 cm. layer, as percentage of initial quantity											
	0–100	—	—	11.6	0.6	—	—	81.5	47.0	89.0	52.2

[1] SO_4'' content of the soil of Kizyl-Arvat Station was not calculated, since salinization here is of the chloride type.

TABLE 2. Influence of leaching on desalinization of crust solonchak[1]

Place of investigation and soil	Soil depth in cm.	Content before leaching (t./ha.)		Percentage of initial quantity remaining after leaching with					
				4,000 m.^{3}/ha.		6,000 m.^{3}/ha.		8,000 m.^{3}/ha.	
		Cl'	SO_4''	Cl'	SO_4''	Cl'	SO_4''	Cl'	SO_4''
Kara-Kalpak	0–50	20.9	161.9	57.4	72.7	44.5	63.2	24.9	55.6
Experimental	50–100	9.0	59.5	141.1	161.7	210.0	184.9	25.0	20.20
Station (crust solonchak)	0–100	29.9	221.4	97.6	96.6	94.3	95.9	92.6	95.0
Salts washed out of 0–100 cm. layer in 90 per cent initial quantity									
	0–100	—	—	2.4	3.4	5.7	4.1	7.4	5.0

[1] For the indicated soil layer, salt reserves were calculated in absolute and in relative terms for each case.

in Cl' form 57.7 per cent of its initial content), whereas with the same quantity on the Tashaouz Station the same layer already represents an horizon of salt accumulation (reserves in Cl': 172 per cent).

As has already been noted, the results of the experiments carried out on the Kara-Kalpak Station are quite different. From the above-mentioned data, it follows that salts are carried out from a layer not deeper than 1 m. Only limited redistribution takes place: from the 0–50 cm. layer a small quantity is carried out; salts return into the 50–100 cm. layer. (These findings are valid both for sulphates and for chlorides.)

The foregoing data show clearly that the transfer of salt during waterings takes place more actively and better when salt solutions migrate in dry ground; when the capillary fringe occurs near to the surface, it is more difficult to effectuate waterings and the carrying away of salts does not effectively take place. In such cases waterings can give a positive effect only with the help of drainage.

RÉSUMÉ

Mouvement des sels facilement solubles dans les solontchaks soumis à lessivage (A. A. Kizilova)

Des expériences ont été faites pour étudier le déplacement d'une solution saline par le lessivage de solontchaks soumis à diverses conditions hydrogéologiques, et pour rechercher dans quelle mesure le déplacement du sel dépend des normes d'arrosage. On a constaté qu'une migration active ne s'est produite que dans une couche d'un mètre; au-dessous, l'arrosage n'a produit aucune modification. En outre, il est apparu que le déplacement du sel au cours des arrosages s'effectue de façon plus active lorsque la solution saline migre en terrain sec. Quand la frange capillaire se trouve près de la surface, il est plus difficile d'effectuer les arrosages et il ne se produit à peu près aucun déplacement des sels. Les arrosages ne peuvent alors donner de résultat positif que si le sol est drainé.

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EFFECT OF SALINE IRRIGATION WATERS ON SOME SOIL PROPERTIES

by

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The present report deals with the first phase of a three-stage programme consisting of laboratory, greenhouse and field studies.

Surface soils of up to 8 inches in depth were collected from areas having the lowest salt concentration; they were then mixed thoroughly, air-dried and passed through a 2 mm. sieve. These soils were analysed for soil *p*H, water soluble Ca + Mg, soluble Na and K, CO_3'', HCO_3', Cl', SO_4'' (by difference), exchangeable Na and K, exchangeable Ca + Mg (by difference) and conductivity of the saturation paste extract by methods described by Richards [39].[1] Cation exchange capacity, $CaCO_3$ content and the particle size distribution were determined by the methods described by the Association of Official Agricultural Chemists [1], Collins [5], and Moodi *et al* [31] respectively. All the results are expressed on an oven-dry basis and are presented in Table 1.

Two series of salts were taken: the first included NaCl and $CaCl_2$, and the second $NaHCO_3$, NaCl and $CaCl_2$. In the first series solutions of NaCl and $CaCl_2$ were prepared in such a manner that the total cation concentrations of Na + Ca were 8, 16, 32, 64 and 128 meq./l. in the ratio of 1 : 1, 2 : 1, 4 : 1 and 9 : 1 respectively, the total number of treatments being 20. In the second series, similar treat-

TABLE 1. The mechanical and chemical composition of the original soil used (oven-dry basis)

MECHANICAL ANALYSIS

Sand	Silt	Clay	Texture
72.2%	13.5%	14.3%	Sandy loam

CHEMICAL ANALYSIS

Saturation paste and saturation paste extract determinations

Saturation	*p*H	Conductivity	Water-soluble ions (meq./100 gm.)						SAR	SSP
			Ca + Mg	Na	K	$CO_3'' + HCO_3'$	Cl'	SO_4''		
%		millimhos/cm.								
33.0	8.1	1.7	0.461	0.165	0.004	0.264	0.304	0.062	2.6	27.0

Cation exchange capacity and exchangeable cations

Cation exchange capacity	Exchangeable ions (meq./100 gm.)			Exchangeable ions		
	Na	Ca + Mg	K	Na	Ca + Mg	K
meq./100 gm.				%	%	%
4.1	0.094	4.004	0.002	2.3	97.64	0.06

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[1] The figures in brackets refer to the bibliography on page 236.

ments were made except that Na was taken as a mixture of NaCl and $NaHCO_3$; in one case the ratio was 1 : 2 and in the other case 2 : 1, so that the difference in the treatments in the two series could be interpreted as due to the presence of HCO_3'. The number of treatments in the second series was 40.

The requisite quantities of the salt mixtures were dissolved separately in 60 ml. distilled water for each treatment, and added to 300-gm. soil samples contained in one-pound capacity Kilner jars. All the soils in the jars were saturated with distilled water and stirred occasionally to facilitate drying: 150-gm. soil samples were drawn from the jars and analysed as before. Part of the data are presented graphically in fig. 1, and in tabular form in Table 2.

RESULTS AND DISCUSSION

The area of these studies is comparable to the areas of low rainfall in which limited irrigation facilities are available and in which loss of irrigation water occurs through evaporation and transpiration without any leaching. Such conditions often occur in West Pakistan, where a limited quantity of water is available for use over larger areas.

As the original conductivity of the soil used was 1.7 millimhos/cm. at 25 °C., the first two concentrations, 8 and 16 meq./l. did not have any appreciable effect on the exchangeable sodium percentage (ESP) (see fig. 1), assuming that the salts added through one irrigation had a concentration of 8 meq./l., but when the concentration increased beyond these limits, there was a marked effect on the ESP. Moreover, fig. 1 shows that relatively large increases in the ESP of soils occurred where the Na/Ca ratio exceeded 1 : 1 and the concentration of water used exceeded 16 meq./l. Fig. 1 also shows that the HCO_3' content of the water used markedly influenced its quality; this is evidenced by the increase in exchangeable Na of the treated soils. The ESP was greater when the HCO_3'/Cl' ratio of the irrigation water was 2 : 1 than when either the anions consisted of Cl' only or when the HCO_3'/Cl' ratio was 1 : 2. The higher ESP may be partially due to the precipitation of soluble and exchangeable Ca as $CaCO_3$, thus resulting in the accumulation of Na in the soil exchange complex.

In Table 2, sodium adsorption ratios (SAR) were worked out from the original Na/Ca ratios, and from the SAR the hazard values were found by the method described by Richards [39]. It will be observed that the SAR and the hazard values for Cl' and Cl' and HCO_3'

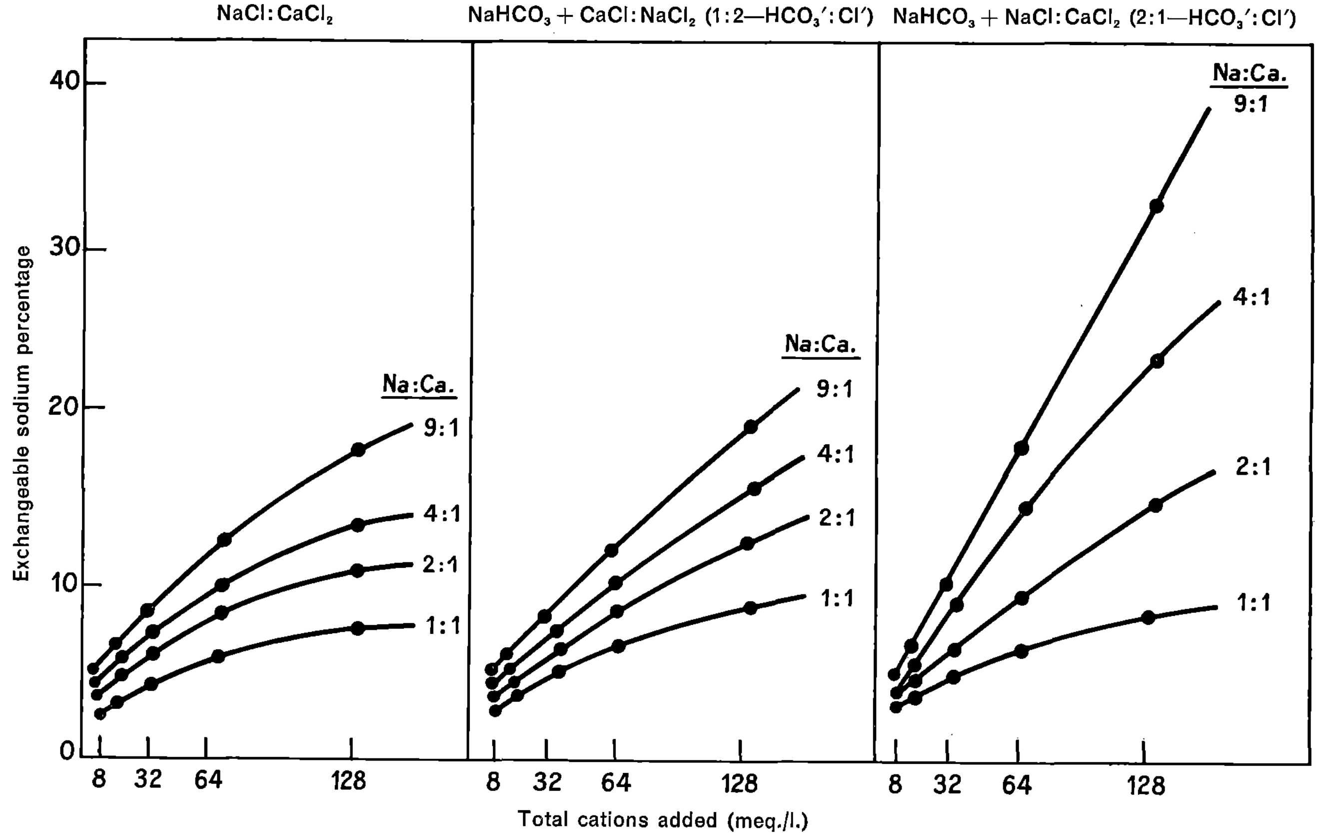

FIG. 1. The effect of the bicarbonate and chloride ions on the equilibrium exchangeable sodium content of soils treated with Na : Ca mixtures of varying total cation concentrations.

TABLE 2. Comparison and classification of water of different compositions based on original and calculated values

Original treatment		Classification based on original composition			Classification based on "effective" composition of water			Observed irrigations[1]
Na : Ca	HCO_3' : Cl'	Estimated conductivity	SAR	Predicted Na hazard	Estimated conductivity	SAR	Predicted Na hazard	
		Micromhos/cm.			Micromhos/cm.			
1 : 1	Cl' only	800	2.1	Low	800	2.1	Low	Very high
2 : 1	Cl' only	800	4.6	Low	800	4.6	Low	100
4 : 1	Cl' only	800	7.1	Medium	800	7.1	Medium	24–28
9 : 1	Cl' only	800	11.4	Medium	800	11.4	Medium	11–13
1 : 1	1 : 2	800	2.1	Low	666	3.5	Low	Very high
2 : 1	1 : 2	800	4.6	Low	622	8.0	Medium	20–24
4 : 1	1 : 2	800	7.1	Medium	640	Infinity	Very high	12–14
9 : 1	1 : 2	800	11.4	Medium	720	Infinity	Very high	7–9
1 : 1	2 : 1	800	2.1	Low	534	5.5	Low	Very high
2 : 1	2 : 1	800	4.6	Low	534	Infinity	Very high	15–17
4 : 1	2 : 1	800	7.1	Medium	640	Infinity	Very high	7–9
9 : 1	2 : 1	800	11.4	Medium	720	Infinity	Very high	5–7

1. Observed irrigations—determined by extrapolation as the estimated number of irrigations to the field capacity with 8 meq./l. water necessary to produce an exchangeable Na level of 15 per cent.

mixtures are identical, because in these calculations no allowance was made for the precipitation of Ca as CO_3''.

Eaton [8], Wilcox [41] and Lewis [28] showed that Na from Na_2CO_3 was adsorbed by soils to a much greater extent than from the neutral Na-salts used in corresponding concentrations. They assumed that when the irrigation water contained more $CO_3'' + HCO_3'$ than Ca + Mg, then after evaporation and transpiration Ca + Mg would precipitate as CO_3'' and that the Na/Ca ratio in solution might become greater than in the water applied. With this idea in view, the effective values for the conductivity and SAR were calculated by deducting the Ca precipitated as CO_3'' from the total original conductivity and from the original Ca concentration of the water used respectively. These new effective values for conductivity, SAR and, to some extent, Na hazard, differ from those calculated according to Richards [39], where HCO_3' was used.

According to Richards [39], 15 per cent exchangeable Na represents the alkali condition in soils. Fig. 1 shows that only a few treatments attained exchangeable Na percentages of this level. In the case of treatments in which the ESP was below 15 per cent, the total meq./l. of the salts to attain this value of ESP was found by extrapolation of the plotted curves to the point where the 15 per cent Na saturation line was crossed. The values for meq./l. were converted into the number of irrigations for each treatment which will create the alkali conditions, assuming that each irrigation is equivalent to 8 meq./l. of the added Na-salt. The number of these irrigations to cause Na hazard is given in the last column of Table 2. Now, when the hazard values calculated according to Richards [39] and those worked out according to the concept of effective values are compared with the values given in the last column, Table 2, it will be noticed that there is a greater agreement between the values found by the effective value concept and the values given in the last column than between those calculated according to Richards [39] and the ones given in the last column.

The last column, Table 2, shows that the irrigation water with a Na/Ca ratio of 1 : 1 could be safely used, even at the HCO_3'/Cl' ratio of 2 : 1. To produce an exchangeable Na level of 15 per cent with a 2 : 1 Na/Ca ratio, a conductivity of about 800 micromhos/cm. and all the neutral salts, approximately 100 irrigations are required. In case of waters in which the HCO_3'/Cl' ratios are 1 : 2 and 2 : 1, 20–24 and 15–17 irrigations will result in the said level of exchangeable Na. With Na/Ca ratios of 4 : 1 and 9 : 1 the case becomes very serious, as with even a few irrigations the level of 15 per cent exchangeable Na will be attained.

The above discussion shows that the standard fixed by the U.S. Salinity Laboratory for the classification of irrigation waters could be improved by adopting the effective conductivity and the new SAR values instead of the original conductivity and the SAR values of the irrigation waters.

Fireman and Wadleigh [15] made a statistical study of extensive data in order to establish a relationship between the soil *p*H and its ESP. From their analysis, they stated that a *p*H of 8.5 or more almost invariably indicated an ESP of 15 or more and the presence of $CaCO_3$, and that the ESP of soils having *p*H values below 8.5 may or may not exceed 15. The data, not presented here, do not support these generalizations. The *p*H values fluctuate between 8 and 8.3 for all treatments, except when Na/Ca ratios are 4 : 1 and 9 : 1 and the HCO_3'/Cl' ratio is 2 : 1. Under these conditions the *p*H values vary between 8.3 and 8.75. The data also show that even for *p*H values lower than 8.5 the ESP is 15 or over.

RÉSUMÉ

Influence de l'eau d'irrigation saline sur certaines propriétés des sols (A. Wahhab)

Au Pakistan-Occidental, de vastes étendues de terrain sont devenues stériles parce qu'elles sont saturées d'eau et de sel.

C'est l'eau d'infiltration provenant des canaux qui est la cause principale de la saturation du sol par l'eau; la présence de sels dans l'eau d'irrigation favorise puissamment leur accumulation dans le profil du sol. Pour récupérer les zones salines ou détrempées, un bon drainage s'impose. En vue d'abaisser le niveau de la nappe phréatique et de résoudre le problème du manque d'eau, des terres appartenant à l'État sont concédées pour une période déterminée, dans le cadre de différents projets, à condition que des puits donnant de l'eau propre à l'irrigation y soient forés.

Des expériences de laboratoire portant sur des échantillons de sols superficiels auxquels avaient été ajoutées des solutions plus ou moins salines ont été effectuées; les résultats de ces expériences sont exposés dans un tableau où sont comparés et classés, d'après les valeurs originales et les valeurs calculées, des échantillons d'eau de composition différente. Il semble qu'on pourrait améliorer les normes proposées par le Salinity Laboratory des États-Unis pour le classement des eaux d'irrigation, en remplaçant par la conductivité efficace et par les nouvelles valeurs du taux d'absorption du sodium la conductivité primitive et les valeurs du taux d'absorption du sodium des eaux d'irrigation.

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EXPÉRIENCE ALGÉRIENNE D'UTILISATION DES EAUX SAUMÂTRES POUR L'IRRIGATION, AVEC RÉFÉRENCE PARTICULIÈRE AUX SOLS SALINS

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AVANT-PROPOS

La présente communication n'a nullement la prétention de présenter un travail original ni d'apporter des éléments scientifiques nouveaux. Le seul but visé est de donner un aperçu d'ensemble, valable pour diverses régions d'Algérie, des problèmes de salinité en relation avec l'agriculture, d'en mettre en évidence les difficultés, et de décrire sommairement les précautions à prendre pour utiliser avec fruit des eaux médiocres sur des sols salins.

Encore que cet examen très général ne concerne que l'expérience algérienne, il n'est pas impossible qu'il puisse, dans une certaine mesure, servir de "toile de fond" à une discussion des travaux scientifiques particuliers. L'Algérie, en effet — on l'a souvent dit avec raison — est un pays de sel. De plus, on y trouve toute la gamme des climats secs et chauds, depuis le subaride de certaines plaines sublittorales, en passant par l'aride déjà bien accusé des hautes plaines steppiques, jusqu'à l'extrême-aride du Sahara central. Si l'on se réfère aux cartes publiées par M. Peveril Meigs[1] dans le cadre des travaux de l'Unesco, il semble bien qu'il y ait une étroite analogie entre le climat de l'Iran par exemple et celui d'une grande partie du pays dont on parle ici.

Cette conjonction d'une aridité plus ou moins sévère avec une teneur en sels généralement notable, parfois très élevée, des eaux et des sols a été, dans le passé, la cause de déboires considérables quand on a rompu des équilibres naturels précaires par l'introduction de l'irrigation sans précautions suffisantes. Elle pose aujourd'hui et depuis bien des années au chercheur, à l'ingénieur et au praticien un difficile problème qu'on ne peut éluder, et l'expérience acquise commence à prendre quelque valeur.

Dans ce qui suit, on examinera successivement: les sols salins; les eaux de différentes origines; l'utilisation en agriculture des eaux plus ou moins salines sur les sols salins.

LES SOLS SALINS

Degré de concentration

Comme dans tous les pays arides ou subarides, l'évaporation rapide de l'eau pendant la saison sèche détermine une accumulation de sels divers dans l'horizon superficiel des sols, celui précisément qu'on cherche à livrer à la culture.

Lorsque la concentration saline de cet horizon reste relativement faible, elle provoque seulement une réduction appréciable de la végétation. La vitalité des plantes, même spontanées, se trouve diminuée. Les cultures à sec présentent d'importantes baisses de rendement. Cette manifestation du "salant" est fréquente, et se produit souvent sur des aires très vastes.

Lorsque les dépôts deviennent plus importants, la concentration en sels arrive à interdire la culture ordinaire, même dans les régions subarides où les précipitations seraient encore à la rigueur suffisantes. Le sol est alors occupé, d'une manière plus ou moins dense, par des peuplements de plantes spécialisées caractéristiques des solontchaks, les halophiles.

Celles-ci constituent en Afrique du Nord trois groupes répondant à des conditions écologiques différentes: *a*) les halophiles grasses ou succulentes (soudes, salicornes et spergulaires); on les rencontre par exemple dans les solontchaks humides des plaines sublittorales d'Oranie; on les trouve aussi dans les hautes plaines steppiques, en bordure de chotts, à la limite de la zone stérile; *b*) les halophiles demi-grasses, représentées surtout par des Salsolacées, spécifiques des solontchaks secs à nappe phréatique profonde, de la région présaharienne (plaine d'El Outaya, près de Biskra, vallée de la Saoura à Igli, plaine d'Abadla sur le Guir, région d'Adrar, etc.); *c*) les halophiles sèches, plus rares en Algérie (certaines armoises et des Graminées résistantes au sel), qui occupent

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[1] Peveril Meigs, "La répartition mondiale des zones climatiques arides et semi-arides", *Compte rendu des recherches relatives à l'hydrologie de la zone aride*. Paris, Unesco, 17 décembre 1952; p. 208–215.

des sols argileux gris lorsque la nappe phréatique est profonde.

Lorsque la concentration saline augmente encore, le sel se dépose à la surface des sols qui peuvent alors être dépourvus de toute végétation. Il se forme, à la fin de l'été, de minces couches blanchâtres ou grisâtres d'efflorescences salines. En certaines régions sahariennes, on peut même observer de véritables croûtes cristallines permanentes. Ces sols sont stériles et pratiquement irrécupérables.

Nature des sels

Comme en d'autres régions analogues, la nature des sels joue un rôle important. Dans nos pays, la salure des sols est le plus souvent d'origine sédimentaire, et le salant résulte de la présence simultanée de plusieurs sels minéraux, ce qui a tendance à augmenter sa toxicité. Cette hétérogénéité rend de surcroît la lutte plus difficile.

Dans les solontchaks de la zone tellienne subaride, les éléments les plus néfastes sont le chlorure de sodium, le chlorure de magnésium, et très souvent une association de ces deux sels. Ils constituent le "salant blanc". Les chlorures sont la plupart du temps accompagnés de sulfate de calcium, dont, en revanche, l'action favorable est souvent appréciable. La présence de ce dernier sel permet en fait de classer la plupart de ces terrains dans la catégorie des solontchaks sodo-calciques. Les solontchaks sodiques ou sodo-magnésiens existent mais sont plus rares.

La richesse relative en sulfate de chaux augmente notablement quand on passe aux solontchaks des bassins fermés des hautes plaines, dans la région des chotts. Mais dans ces régions, l'action bénéfique de ce sel est malheureusement réduite par suite des conditions locales: concentration saline générale plus élevée, climat plus sec et plus chaud.

Dans les régions présahariennes et sahariennes, le climat favorise la formation de carbonate de soude et l'apparition du "salant noir". Le carbonate de soude, qui peut être associé au sulfate de soude, au sulfate de magnésie, au chlorure de calcium, agit comme un énergique défloculant, rend les sols imperméables, asphyxiants, et incapables de donner vie à la moindre végétation.

Il arrive que le salant blanc rende un sol stérile, mais ce phénomène est rare; en fait on y voit presque toujours des groupements halophiles plus ou moins résistants, dont la composition floristique et le degré de couverture varient avec la toxicité du milieu. Sur les taches de salant noir, au contraire, la nudité totale du sol, à part dans certains cas quelques végétaux inférieurs quasi invisibles, est la règle absolue.

Heureusement, le phénomène du salant noir est rare à l'état naturel dans nos régions. Cependant, il peut apparaître sur de vastes aires, à la suite d'irrigations mal conduites, en saison chaude, sur des sols ayant reçu des fumures, ou des apports naturels de matière organique, par dépôts de crues par exemple.

Structure des sols

L'aspect superficiel d'un sol salin ne saurait suffire pour formuler un pronostic sur l'aptitude d'un tel sol à une certaine mise en valeur.

Cette aptitude est notamment sous la dépendance étroite de la perméabilité. Quant il s'agit de ces sols particulièrement difficiles, l'étude de nombreux profils pédologiques est plus indispensable encore qu'en ce qui concerne des sols sains. Pour des raisons diverses et bien connues des spécialistes, les unes purement physiques, les autres physico-chimiques, tenter de mettre en culture, et surtout en culture irriguée, un sol salin argileux, constitue en général une entreprise quasi désespérée. Une simple couche argileuse, parfois très mince mais mal placée, peut suffire à compromettre tout effort, à moins qu'une bonne connaissance du problème, avec un peu de chance, permette de trouver une solution économiquement acceptable.

LES EAUX DISPONIBLES

Les précipitations naturelles

Dans toutes les régions subarides de l'Algérie où les précipitations ne sont pas négligeables, leur principal intérêt est de provoquer, pourvu qu'on ait un bon drainage, un lessivage de la couche superficielle du sol.

Leur utilisation directe pour l'agriculture est très aléatoire, à cause de l'irrégularité du climat. Dire par exemple qu'une région reçoit en moyenne 350 mm de pluie, cela signifie que certaines années, ou même certaines séries d'années, il ne tombera que 150 ou 200 mm, ce qui est très insuffisant pour la croissance de la plupart des plantes utiles. Même quand la hauteur totale de pluie sur l'année agricole serait à la rigueur convenable, il est rare que les averses tombent aux moments les plus favorables. Quand, dans ces régions, on tente quelques cultures, ce sont toujours des céréales (blé ou orge): le rendement moyen sur dix ans est toujours extrêmement faible. On peut parfois réussir quelques cultures arbustives peu exigeantes et très résistantes, par exemple celles de l'olivier, du grenadier, quelquefois du palmier. Il convient de donner aux arbres un vaste "espace vital". Les rendements sont généralement très médiocres.

Dans les régions sahariennes, la pluie ne présente, à l'égard des cultures, aucun intérêt pratique.

L'eau des barrages-réservoirs

Beaucoup de nos zones d'irrigation situées dans les plaines sublittorales de climat subaride, en Oranie surtout, sont alimentées en eau régularisée par des réservoirs dépendant de bassins mieux arrosés.

Cependant la plupart de ces eaux contiennent des quantités de sels non négligeables, par exemple: l'oued Chéliff (au barrage de dérivation de Charon, de 900 à 1200 ppm; l'oued Mina (barrage-réservoir de Bakhadda), de 700 à 1150 ppm; l'oued Habra (barrage-réservoir de Bou-Hanifia), de 450 à 750 ppm; l'oued Mékerra (barrages-réservoirs du Sarno et des Cheurfas), de 1200 à 2500 ppm.

Ces eaux, à part celle de la Mékerra en période estivale, sont utilisables sans grandes précautions spéciales dans les sols très sains de pieds de coteaux. Mais leur application dans les basses plaines où les sols salins sont en abondance pose des problèmes difficiles.

L'eau des nappes souterraines

C'est surtout au Sahara que l'agriculture est sous la dépendance des eaux souterraines, malgré le prix de revient élevé du prélèvement, car les nappes constituent la seule ressource utilisable.

La teneur en sel de ces eaux est essentiellement variable suivant les régions et les aquifères sollicités.

La très belle ressource du continental intercalaire (infracénomanienne) donne au Sahara les eaux les plus abondantes et les meilleures. Cette nappe, qui existe sous de vastes régions de la moitié nord de l'Afrique, se rencontre à des profondeurs très variables, depuis la profondeur quasi nulle puisqu'il existe des zones d'affleurement (Touat, Tidikelt) jusqu'à des milliers de mètres comme c'est le cas aux approches du bas Sahara (méridien de Biskra).

En dehors des zones d'affleurement, la nappe est captive sous le toit cénomanien marneux, et, quand la cote du sol est assez basse, fortement jaillissante. Certains de nos forages artésiens à utilisation agricole ont plus de 2000 m de profondeur et donnent par jaillissement des débits de l'ordre de 200 l/s.

Quand on est loin des affleurements, la composition saline de l'eau est assez constante, et varie peu autour de 1500 ppm. En revanche, tout près des zones d'affleurement la salure peut atteindre 3000 ppm.

Une autre ressource intéressante, dans une région déjà fort exploitée, est celle du "faisceau" de nappes de l'éocène et du continental terminal de l'oued Rhir dont les eaux sont déjà très chargées (4700 ppm à Tougourt).

Enfin, on est parfois amené à utiliser des nappes d'autres gisements, ainsi que, lorsqu'elle existe, la nappe phréatique. Toutes les eaux qui en proviennent sont peu ou prou chargées en sels. C'est ainsi que la nappe d'accompagnement de la Saoura à Adrar donne des eaux dont la salure, qui change avec la saison, varie de 3000 à 7000 ppm.

Remarque générale

Ce qui précède montre qu'on n'a jamais affaire à des eaux vraiment douces. Toutes contiennent des sels, parmi lesquels domine le chlorure de sodium, mais accompagné le plus souvent d'ions très divers dont la conjonction n'est pas toujours favorable.

Beaucoup de ces eaux, qu'il faut chercher à utiliser parce qu'on n'a rien d'autre, seraient déjà suspectes ou dangereuses sur des sols très sains. Quand on les épand sur des sols salins, il faut s'entourer de précautions extrêmement sévères pour en tirer un profit quelconque, soit qu'on tente une véritable mise en irrigation, soit qu'on se propose simplement de transformer une végétation naturelle impropre à tous usages en une autre qui permette de faire pacager les animaux domestiques.

RAPPORTS DE L'EAU ET DU SOL. PRÉCAUTIONS A PRENDRE. TECHNIQUE CULTURALES RECOMMANDABLES

Dès qu'on se trouve placé dans des conditions plus ou moins accusées d'aridité et de salinité, il est extrêmement difficile d'opérer des classements, de généraliser des résultats d'expériences et de préconiser des méthodes sûres. On peut dire que chaque cas est particulier: il faut l'étudier pour lui-même, dans un véritable esprit scientifique, mais sans grand espoir de réussir du premier coup.

L'ensemble climat-eau-sol-plante doit être pris comme un tout. En ce qui concerne notamment l'eau et le sol, il est absurde, dans des limites assez étendues et en écartant les cas extrêmes et non douteux, de dire, sur la foi des analyses, que telle eau est bonne ou mauvaise, tel sol bon ou mauvais. Une eau est bonne ou mauvaise en fonction d'un sol donné et inversement. Nous avons vu, dans une plaine voisine d'Oran, où, il est vrai, les conditions édaphiques étaient excellentes, des orangers s'accommoder parfaitement d'une eau dont la teneur saline était supérieure à 2500 ppm. Nous avons vu, en revanche, le salant apparaître et la végétation disparaître sur des sols d'apparence honnête irrigués avec des eaux peu chargées: c'est que les propriétés du sol avaient été mal étudiées.

Ce que l'expérience apprend de plus certain, c'est que, dans tous ces cas douteux et un peu "limites", on doit se montrer très circonspect et mettre toutes les chances de son côté avant d'entreprendre une œuvre d'irrigation.

Une mention toute spéciale doit être faite de la nappe phréatique. Le danger des remontées de nappes est bien connu de tous les praticiens de l'irrigation. Mais ce danger devient incomparablement plus grave lorsqu'il s'agit de nappes salées. Non seulement la destruction de la végétation est plus rapide, mais il se produit parfois des désastres brutaux et à peu près irréversibles. On ne saurait trop insister sur ce point.

Encore que les raisons profondes du phénomène soient difficiles à analyser, on assiste quelquefois, en région irriguée subaride et saline, à la suite soit de pluies anormalement violentes et longues, soit d'une inondation, soit d'irrigations mal contrôlées, à une apparition et à une extension presque soudaine du salant par remontée de la nappe salée. On a l'impression d'une sorte de "débordement souterrain", qui ne doit pas être sans relation avec l'hétérogénéité de structure du sous-sol, de règle dans nos plaines irriguées, généralement installées sur des champs d'épandage imbriqués les uns dans les autres. Les effets des crues de 1903 n'ont pas disparu dans les plaines d'Oranie. Les inondations de 1927, qui ont provoqué la rupture du barrage de l'oued Fergoug, ont eu dans la plaine de Perrégaux des conséquences néfastes dont les traces demeurent. A une moindre échelle, on a pu connaître des déboires analogues, à la suite de submersions artificielles intempestives.

Dans toute tentative de mise en culture irriguée dans les conditions qui nous occupent, il sera donc indispensable d'étudier le niveau des nappes phréatiques, d'essayer de préciser leurs conditions d'alimentation et d'écoulement, et de mesurer le risque de remontée lors du changement d'équilibre naturel par apport d'eau nouvelle. Négliger cette précaution fondamentale, ce serait courir délibérément à l'échec. Ajoutons que le drainage, dont il sera question maintenant, ne suffit pas toujours à neutraliser les phénomènes brutaux dont on vient de parler.

Le drainage est fondamental. Il doit être étudié avec soin et réalisé avant toute irrigation. Dans les cas difficiles, il sera bon de se donner une marge sérieuse, et de mettre le fond des drains à deux mètres au moins en moyenne de la surface du sol.

Mais cela suppose que les terrains veuillent bien se laisser drainer, ce qui n'est pas toujours le cas. D'où l'intérêt de l'étude pédologique préalable sur coupes judicieusement placées d'après l'examen de surface, et soigneusement étudiées. On a dit plus haut que le succès ou l'échec dépendait parfois d'un détail, par exemple de la présence à un niveau fâcheux d'une couche imperméable, même mince. Parfois il est possible de s'en affranchir ou de réduire le risque par un travail approprié. Malgré tout, les eaux les plus chargées ne pourront être utilisées que sur des sols très perméables, même si ces derniers sont salins: ces conditions se rencontrent souvent, heureusement, au Sahara.

Dans les cas où le sol, sans être trop argileux, n'est tout de même pas apte à subir un drianage rapide, éventuellement un lessivage, si celui-ci est nécessaire, on peut penser à en modifier la structure par certains amendements. Le plus simple de ces amendements est le sable, quand on en a (sable dunaire au Sahara). Il semble que, dans certains cas, l'incorporation à l'eau d'irrigation de fines moutures de gypse, méthode employée dans certaines régions de Californie, puisse donner des résultats. Enfin, la pratique de l'enfouissement d'engrais verts est généralement à conseiller, ainsi que l'emploi de fumures organiques (souvent fumier artificiel pailleux).

En matière de fumure, il ne faudra employer les engrais chimiques qu'avec beaucoup de circonspection: il peut être dangereux d'ajouter de nouveaux ions parasites, aux réactions difficiles à prévoir, dans la solution du sol qui n'est déjà que trop chargée.

Pour pouvoir rester maître de la quantité d'eau qu'on donne au sol, et notamment pour éviter de favoriser les remontées de nappes, il est indispensable que l'eau soit conduite dans des canalisations étanches.

C'est une des raisons (non la seule, bien entendu) qui nous a conduits, en Algérie, à installer tous nos réseaux d'irrigation en respectant cette condition. On a même abandonné les canaux simplement creusés et revêtus au profit de conduites et de canaux faits d'éléments préfabriqués en usine.

En conditions salines, cette question a d'autant plus d'intérêt que les plus belles réussites sont généralement obtenues en terrains très perméables.

La réussite est largement conditionnée par une excellente préparation du sol. Le nivellement et le surfaçage doivent être très soignés. Cela permet en effet: d'éviter les tâches saisonnières de salant, ou tout au moins d'en réduire les effets; de rendre plus efficaces les irrigations de lessivage quand on a décidé d'en faire; de permettre, une fois le sol aménagé et les cultures entreprises, la plus grande économie d'eau, non pas tellement à cause de son prix, mais surtout parce que cela correspond à une "économie de sel".

Les principales techniques d'irrigation ont presque toutes leur rôle à jouer suivant les cas. C'est une question de bonne adaptation.

La submersion non dirigée, avec canaux permanents, est parfois employée dans les plaines du Tell, sur des solontchaks sodo-calciques à sous-sol sablonneux, non pas pour faire de la culture irriguée proprement dite, mais pour transformer les landes à soudes en prairies à fétuques et les rendre ainsi propres au pacage.

La submersion dirigée est fréquemment utilisée. On la réalise soit en larges bandes (25 à 30 m de large sur 80 à 100 m de long) pour la culture de céréales dans le Tell, soit en planches qui peuvent être: étroites et longues — 4,50 m à 5 m de large — cultures de céréales dans le Tell, palmeraies au Sahara, étroites et courtes (luzernières dans le Tell), carrées (cultures d'oasis sahariennes: céréales, maraîchage, tabac, etc.).

L'irrigation par infiltration peut être effectuée soit par planches billonnées (les billons, espacés d'un mètre environ, constituent de véritables bourrelets); soit par rigoles et séguias, dont l'intervalle est disposé en un billon large (90 cm environ) et aplati au madrier.

Dans les deux cas, le but visé est la création d'un milieu relativement sain, favorable à une germination ou une bonne reprise des plants, et à un départ plus aisé de la végétation.

Ces procédés, très utilisés dans les sols salins des plaines telliennes (culture de l'artichaut, du cotonnier, etc.), ont donné satisfaction dans les solontchaks sahariens pour les cultures maraîchères.

Dans certains cas extrêmes, on est parfois amené à disposer d'abord le terrain en bandes ou en planches pour opérer des submersions de lessivage, avant de le billonner pour la culture.

Enfin, lorsque des eaux à salure saisonnièrement variables sont épandues sur des sols de perméabilité médiocre, on peut utiliser le paillage, qui permet d'économiser les arrosages durant la période où la concentration est la plus forte. Cela suppose généralement un lessivage ultérieur avec des eaux moins chargées.

Il est bien entendu qu'on doit prêter attention à la nature des plantes à cultiver et, dans chaque espèce, sur les variétés les plus résistantes au sel. On n'insistera pas ici sur ce point, qui fera certainement l'objet d'intéressantes communications.

Il ne viendrait évidemment à l'idée de personne de cultiver des haricots sur un sol salin avec de l'eau salée. A l'autre extrême, on sait que le palmier dattier tolère fort bien des eaux à 6000 ou même 7000 ppm. S'agissant de plantes plus ou moins tolérantes, il est difficile de dresser une échelle valable pour tous les cas. Les conditions édaphiques sont extrêmement importantes, et l'on a parfois d'heureuses surprises.

Pour terminer ce chapitre, on insistera sur la nécessité d'une très grande précision et d'une attention soutenue dans la pratique même des irrigations, la fréquence et l'abondance des arrosages. Le praticien doit être un observateur averti, il ne doit jamais oublier que les résultats d'une campagne, dans les cas difficiles, peuvent être irrémédiablement compromis par une maladresse ou un manque de surveillance.

CONCLUSION

Arrivé au terme de ce court exposé, on peut le trouver assez décevant. On voit assez bien cependant ce qu'il ne faut pas faire, et c'est déjà un résultat. Mais il est beaucoup plus difficile de déterminer ce qu'il faut faire, pour la raison, déjà indiquée, que cela dépend de la conjugaison de nombreux facteurs, dont l'effet n'est pas toujours concordant.

L'ensemble sol salin et eau salée sous un climat aride peut se comparer en quelque sorte à un organisme affecté de maladies multiples: une médication destinée à soigner une de ces affections risque de tuer le patient parce qu'elle est contraire à une autre. On ne peut essayer d'améliorer la situation que grâce à une profonde compréhension du tempérament du malade et de ses réactions physiologiques. Or, il y a à peu près autant de tempéraments que d'individus. On peut arriver à en faire une manière de classement, mais c'est très difficile, et l'on risque toujours en généralisant de laisser dans l'ombre un point particulier et essentiel.

En culture sous conditions arides et salines, on ne rencontrera pas plus de panacées qu'en médecine. Ce qui est fondamental, c'est de poser le diagnostic exact, et il faudra pour cela s'aider de toutes les connaissances en matière de chimie, de pédologie, de physiologie végétale et de bien d'autres disciplines. Après quoi, l'échec, ou le succès, dépendra de l'application judicieuse de bons vieux remèdes éprouvés dont il faudra suivre pas à pas les effets.

Cette image ne vaut que ce que valent les images. Pour leur bonheur, pédologues et agrologues peuvent, eux, expérimenter. Il est extrêmement utile parfois de laisser mourir les plantes, pour comprendre pourquoi elles meurent. Cette question d'expérimentation fait l'objet en Algérie d'une attention soutenue. C'est pour promouvoir cette expérimentation qu'ont été installées la station d'étude des sols salins des Hamadénas, dans le bas Chéliff en Oranie, et les stations sahariennes d'Adrar et d'Igli dans la Sahoura.

Il existe certainement beaucoup de stations analogues de par le monde, dont certaines sont très connues, d'autres moins, et d'autres peut-être pas du tout. Il serait éminemment utile d'en faire un inventaire complet et de renforcer les échanges scientifiques et techniques entre ces différents organismes: le progrès, dans ce chemin semé d'embûches, en dépend étroitement.

SUMMARY

Algerian experience of the utilization of brackish water for irrigation, with special reference to saline soils (Georges Drouhin)

In Algeria, cultivable soils are often salted, and most of the water used for irrigation contains a quantity of salts which varies but is always sufficient to require special precautions in its use. This is particularly true of the large part of the country in which the climate is arid or sub-arid.

Saline soils of the solonchak type carry a natural vegetation of halophilous plants. The principal salts are sodium chloride and magnesium chloride, which produce a "white crust". Where sodium carbonate emerges, in very dry regions, a "black crust" is formed which makes the soil absolutely barren. The degree of permeability of soils is also very important for "irrigation" farming.

Rain-water is of hardly any use to vegetation; it occurs too rarely and is ill-distributed. The main service it performs is to wash the surface of the soil. Water from barrage reservoirs (all but one of which are situated in the northern zone) is always somewhat brackish. Ground-water, used for agriculture mainly in the Sahara region, has a variable but often high salt content.

Irrigation under these difficult conditions calls for a serious and thorough prior study of the interaction of water, soil and plant life.

The rise of phreatic ground-water can be disastrous if the water is brackish. The phreatic water table must be carefully watched.

Irrigated soils must be drained before they are planted. Certain improvements (sand, finely ground gypsum, etc.), as well as the ploughing in of green manures and the use of farmyard manure, are to be recommended.

Irrigation water must be brought in through watertight canals, in order to avoid wastage and penetration of the phreatic water table. The soil must be properly prepared (levelling and surfacing). Use of the principal irrigation techniques (submersion, infiltration, etc.) depends on the individual case. Frequent leaching is necessary.

Under the difficult conditions of Algeria, preliminary study and experiment are indispensable for any attempt to use water having any considerable salt content in order to fit saline soils for farming.

DISCUSSION

H. Schoeller. Est-ce qu'il n'y aurait pas intérêt à étudier l'influence, d'une part, des plantes à racines profondes, d'autre part, des plantes à racines peu profondes, sur la migration des sels dans les sols, et à comparer leurs effets? S'il y avait des différences d'influence, cela permettrait d'employer, dans certains cas, des plantes à racines profondes et, dans d'autres cas, des plantes à racines peu profondes.

G. Drouhin. En pratique, on a tendance à cultiver des plantes à racines peu profondes, car, en terrain salin, il n'est pas extrêmement difficile de rendre saine une couche superficielle peu épaisse de sol.

Il y aurait certainement intérêt à étudier le rôle des plantes à racines profondes en ce qui concerne l'amélioration des sols salins. La difficulté est de trouver de telles plantes résistant convenablement au sel et adaptées au climat aride.

T. Jewitt. Would the author please give a very general statement on the methods of drainage used?

G. Drouhin. Les drains principaux et collecteurs, établis techniquement par les pouvoirs publics, sont toujours des canaux ouverts. On n'a pas trouvé de système plus économique, mais il faut reconnaître que l'entretien en est coûteux.

Les propriétaires assurent le drainage intérieur de leur propriété et le raccordement au réseau général. Un certain nombre ont réalisé des systèmes de drainage en poterie: c'est assez rare. Quand le terrain s'y prête, on emploie parfois le sous-solage à l'obus. Dans la plupart des cas, il s'agit de fossés ouverts.

ESSAIS SUR L'IRRIGATION A L'EAU SAUMÂTRE RÉALISÉS AU MAROC

par

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Le problème de l'irrigation à l'eau saumâtre s'est posé avec acuité au Maroc lors de la mise en service du périmètre irrigué des Béni Amir situé dans la cuvette du Tadla, à 200 kilomètres au sud de Rabat.

Eaux d'irrigation. En effet, les eaux de l'oued Oum er Rbia, utilisées pour les irrigations de ce périmètre, contiennent des doses notables de sels. La teneur en chlorure (anion prédominant), exprimée en NaCl (en g/l), varie à la fois suivant les saisons et d'une année à l'autre. Elle décroît pendant la période hivernale (froide et humide) et augmente pendant la période estivale (chaude et sèche), la moyenne oscillant autour de 0,8 ‰. C'est au printemps que la teneur en sels des eaux devient la plus basse (autour de 0,2–0,3 ‰); elle croît ensuite en été pour atteindre son maximum en automne (autour de 1,2–1,5 ‰) et diminue de nouveau en hiver. D'une manière générale, le rapport Mg/Ca est supérieur à 1. Le taux des carbonates de calcium et de magnésium varie peu au cours de l'année. Celui des sulfates est faible.

Sols. On peut diviser les sols des Béni Amir en deux groupes suivant leur épaisseur [4][1]: *a*) sols bruns et châtain rouge à croûte (stalactiforme, nodulaire ou lamellaire) et de faible épaisseur qui occupent les pourtours; *b*) sols bruns profonds sur limon calcaire, généralement encroûté, parfois à croûte graveleuse qui couvrent le centre de la plaine. A titre d'exemple, la composition physique de ces sols (en pourcentage) est indiquée dans le tableau 1.

Il faut signaler que, dans le sol à croûte B–29, le calcaire des horizons terreux se trouve sous forme assez grossière ("pointes calcaires"), tandis que, dans le sol profond B–236, il est très fin. Le complexe absorbant de ces sols est bien saturé en calcium, le taux de sodium échangeable étant très faible (inférieur à 2 ‰). En revanche, les horizons profonds sont riches en magnésium échangeable (au-dessus de 40 ‰ de la capacité d'échange des bases). A l'origine, ces sols n'étaient pas salés.

Tableau 1. Composition physique des sols

	Argile	Limon	Sable fin	Sable grossier	CO_3Ca
B–29 Sol châtain rouge à croûte stalactiforme					
0–10 sol	29	9	41	2	19
10–30	32	10	36	1	21
30–120 croûte stalact.	25	7	18	t	50
120–160	20	8	10	t	62
B–236 Sol brun steppique profond à croûte graveleuse					
0–10	29	25	27	2	15
10–30 sol	29	25	28	2	15
30–60 croûte gravel.	31	17	21	2	30
60–110 limon encroûté	22	17	12	1	46
110–150	28	19	14	1	34

Climat. La région des Béni Amir jouit du climat méditerranéen méridional (hiver pluvieux, été sec), dans sa variété sèche. Ce climat est nettement semi-aride, et son aridité semble s'accentuer quand on va vers l'ouest. A Dar Ould Zidouh (voir les données climatiques), situé au sud-ouest du périmètre, l'indice pluviométrique annuel de Lang s'abaisse à 14,5 pour une pluviométrie de 293 mm; les pluies tombent, en majeure partie, entre novembre et mars, à une époque où la température reste douce. L'été est très sec (en dehors de quelques orages incertains) et particulièrement chaud.

Données climatiques (1930)

Moyennes annuelles: pluies, 293 mm; température, 20°2; P/T, 14,5.

Saison humide (5 mois, de novembre à mars): P/T, 35.

Problèmes à résoudre. Ces conditions du milieu, la faible épaisseur des terres, leur nature, la salure des eaux de

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[1] Les numéros entre crochets renvoient à la bibliographie en fin d'article.

l'Oum er Rbia, la chaleur et la sécheresse de l'été ont motivé les recherches que nous avons entreprises à différentes reprises et qui avaient pour buts principaux et immédiats de déterminer: *a*) si les sels solubles apportés par l'eau d'irrigation s'accumulent dans le sol, c'est-à-dire si l'on doit craindre ou non la salinisation progressive de ces terres; *b*) dans le cas où les sels se seraient effectivement accumulés, si les pluies d'hiver les éliminent au cours des mois d'hiver; *c*) si un échange est possible entre les bases du sol et celles de l'eau et si, en particulier, il peut y avoir fixation par le sol du sodium contenu dans cette eau, c'est-à-dire s'il existe des risques de solonetzation de ces sols et si, dans ce cas, le calcium de ces sols calcaires jouera ou non un rôle protecteur.

DESCRIPTION DES ESSAIS

Essais au laboratoire

La première série d'essais a été réalisée, il y a dix-huit ans, au laboratoire, dans des buses de 40 cm de profondeur sur le sol brun châtain à croûte stalactiforme et sur place aux Béni Amir [1]. Dans ces essais, les irrigations à l'eau salée (dont la salure a été ramenée à 1,5 g/l de NaCl) alternaient avec les arrosages à l'eau distillée qui représentaient les pluies d'hiver, en vue d'établir les possibilités du lavage hivernal. Dans tous ces essais, les volumes d'eau d'irrigation dépassaient largement la capacité de rétention du sol pour l'eau. Au cours de l'expérience, nous faisions varier les volumes et la salure de l'eau d'irrigation. Tous nos essais au laboratoire ont été faits avec de l'eau dont la salure restait constante et élevée au cours des opérations. Les détails de cette expérience sont exposés dans notre *Étude expérimentale de l'irrigation du sol des Béni Amir*. Nous reproduisons dans ces pages nos conclusions de cette étude, qui sont les suivantes:

1. En ce qui concerne les irrigations elles-mêmes, l'arrosage à l'eau salée contenant 1,5 g/l de NaCl ne contribue pas, dans les conditions de l'expérience, à la rétention massive des sels. En revanche, les sels restés dans le sol après chaque arrosage sont susceptibles de remonter vers la surface et de s'accumuler dans les horizons supérieurs.
2. Au cours de la saison pluvieuse, les sols sont susceptibles de subir un lavage plus ou moins complet.
3. Les sels de l'eau d'irrigation agissent sur le sol en provoquant l'augmentation de l'alcalinité et du *p*H, l'apparition de la turbidité de l'eau de percolation dues à l'adsorption (au moins partielle) du sodium.

   Le calcium du calcaire n'intervient dans ces sols que dans une faible mesure; en revanche, l'action protectrice du calcium de l'eau est beaucoup plus marquée. C'est surtout au cours du lavage que se produit la mise en suspension de l'argile et son entraînement.
4. Les irrigations telles qu'on les pratique actuellement aux Béni Amir semblent relever le niveau de la nappe phréatique au cours de l'été car cette remontée coïncide avec le début de la saison des irrigations. La salure de la nappe augmente au cours de l'été et atteint son maximum au cours de l'hiver, probablement par le fait du lavage des sols irrigués; puis elle s'abaisse au printemps.

En comparant les résultats de laboratoire à ceux qu'on observe sur place, on note qu'en général ils concordent. Mais l'ampleur du phénomène est différente suivant qu'on a affaire à des petites buses ou à des parcelles d'essais qui ont une superficie plus importante. Les chiffres trouvés au laboratoire montrent la possibilité de l'accumulation des sels dans les horizons supérieurs. Seulement le taux de chlorures retenus dans les terres des buses est faible, tandis que les déterminations faites sur place révèlent des doses plus élevées. Cela tient à ce que dans les Béni Amir (où l'air est très sec) l'évaporation est plus importante que dans les essais au laboratoire à Rabat.

En ce qui concerne le lavage des terres par les pluies, les résultats sont concordants. L'étude de la salure de la nappe laisse supposer que le lessivage est plus lent dans la nature que dans les buses.

En outre, les trois facteurs suivants influent sur la dynamique des sels dans le sol:

1. Nature des eaux d'irrigation: plus les eaux sont salées, plus il reste de sels dans le sol;
2. Volume et fréquence des irrigations: le lavage partiel des sels se fait plus énergiquement quand le volume est plus grand; en outre, plus les irrigations sont fréquentes, plus rapidement le sol est lavé et plus il est facile de maintenir la salure basse;
3. Quantité d'eau retenue dans le sol après le lavage (autrement dit après les pluies hivernales), qui diminuerait la concentration en sels des eaux d'irrigation.

Étude de la relation entre la salure des sols, celle de l'eau d'arrosage et le régime des irrigations.

Les résultats obtenus au cours de cette étude expérimentale ont incité M. Cherotzky et moi-même à rechercher une relation entre la salure du sol, celle de l'eau d'arrosage et le régime des irrigations [3]. Cette relation s'exprime en une formule qui montre que, si le drainage du sol est assuré, la teneur en sels du sol tend vers une valeur limite k inférieure à la quantité totale des sels apportés par des eaux d'arrosage au cours des irrigations. La valeur chiffrée de cette limite dépend à la fois des propriétés hydriques du sol, de la salure des eaux d'irrigation et du rapport entre le volume d'eau d'arrosage et le volume d'eau retenu dans le sol après chaque irrigation. Plus ce rapport se rapproche de 1, c'est-à-dire plus le volume d'eau d'arrosage se rapproche du volume correspondant à la capacité de rétention, plus le salage du sol sera élevé. Il résulte aussi de cette formule que les irrigations massives des sols salés à l'eau saumâtre peuvent même abaisser dans une proportion notable la salure initiale du sol.

Études réalisées sur place aux Bêni Amir

La nappe des Béni Amir était généralement profonde avant la mise en eau du périmètre. L'irrigation, mal étudiée, de la partie est des Béni Amir a provoqué une alimentation à la nappe, supérieure aux possibilités d'évacuation, et, par suite, sa remontée dangereuse dans le périmètre lui-même, à l'ouest et en aval du périmètre. Des drains ont été creusés pour évacuer, imparfaitement d'ailleurs, les eaux souterraines excédentaires. Malgré la disparition de certaines résurgences à la suite de travaux de drainage, certains accidents de végétation dus à la salure ont été constatés ces dernières années. Au début de 1955, le Centre de recherches agronomiques de Rabat a repris, à la demande de l'administration, les recherches aux Béni Amir sur la dynamique des sels au cours des années 1955 et 1956 [2, 5].

1. Étude de l'évolution de la salure par prélèvement périodique (quatre fois par an) des échantillons de terres en 16 stations d'étude sur des soles différentes de chaque station, et par détermination sur place de l'humidité du sol au moment du prélèvement ainsi que des taux de chlorures, de sulfates et de carbonates.
2. Prélèvements et analyses d'eaux d'irrigation et d'eaux de drainage en différents points du périmètre.
3. Prélèvements (une fois par an) de terres de la couche arable en vue de leur analyse détaillée (caractères physiques, nature du complexe absorbant, matière organique).

Cette étude nous a amené aux conclusions suivantes:

1. Les recherches sur place concernant la dynamique des sels et l'évolution des sols aux Béni Amir sous l'effet des irrigations ont pleinement confirmé les conclusions, exposées plus haut, de notre étude expérimentale de 1940–1941 et les craintes qu'elles exprimaient, à savoir: la possibilité de la remontée de la nappe (soit par suite de la perte d'eau dans les canaux, soit à cause des irrigations massives) suivie du salage des sols, conformément au programme ci-dessous.
2. Les sols du périmètre irrigué des Béni Amir contiennent des proportions notables de chlorures: en moyenne leur taux exprimé en NaCl dépasse largement 1‰. La salure augmente et devient même un obstacle pour les cultures dans les zones où la nappe, malgré les travaux de drainage, reste près de la surface du sol. Dans ces zones, où elle dépasse largement 2‰, les horizons du sol au-dessus du plan d'eau restent constamment humides au cours de l'été, même dans les parcelles non irriguées, ce qui facilite la remontée des sels et leur accumulation dans la couche arable.
3. La remontée des sels et leur accumulation dans les horizons supérieurs ont lieu aussi bien dans les sols non irrigués (jachère) ou irrigués au printemps seulement (céréales, légumineuses) que dans les sols irrigués en été (coton), exception faite des luzernières, où la salure des sols se maintient à un niveau relativement bas.
4. Aucun salage excessif n'a été observé dans les zones où la nappe est profonde, pas plus dans les sols irrigués que dans les sols en jachère non irrigués.
5. En ce qui concerne les variations de la salure au cours de l'année, il existe une différence de comportement entre les sols salés à nappe superficielle et les sols peu salés à nappe profonde, quelle que soit la culture. Dans les sols salés, la dynamique des sels est caractérisée par les traits suivants: au mois d'avril de cette année (1955), la salure des horizons supérieurs (0–40) était égale (céréales, luzerne) ou inférieure (jachère, légumineuses) à celle des horizons inférieurs. Dès le mois de juin, les horizons supérieurs sont devenus plus salés que les horizons inférieurs dans tous les sols non irrigués (jachère, après juin), irrigués au printemps (céréales, légumineuses) ou irrigués tout l'été (coton). Toutefois, dans la sole de luzerne, on constate un fort lessivage au cours de la période d'irrigation (septembre et décembre). En revanche, dans tous les sols peu salés, la salure des horizons supérieurs reste généralement égale ou inférieure à celle des horizons profonds, quelle que soit la culture; ni la remontée des sels ni leur accumulation dans les horizons supérieurs ne s'y produisent.
6. En ce qui concerne l'influence de la salure des eaux d'irrigation sur la solonetzation éventuelle des profils on peut remarquer que, dans ces sols à calcaire fin, le pourcentage du sodium échangeable reste faible (4% en moyenne). En revanche, le taux du magnésium échangeable augmente dans certains cas. Dans ces terres, l'adsorption du magnésium se fait aux dépens du calcium échangeable. L'augmentation du taux de magnésium échangeable semble être due à sa migration vers le haut sous l'effet de l'irrigation des horizons profonds, dont le complexe absorbant est riche en cet élément.
7. L'étude des caractères de la couche arable montre le "grossissement" de la structure sous l'effet de l'irrigation. Il semble aussi que la remontée de la nappe a provoqué les conditions favorables au phénomène de "tirsification" et que nous assistons à ses débuts. Ce phénomène se traduit par le grossissement de la macrostructure, l'augmentation de la compacité, l'apparition du phénomène de foisonnement des mottes et le jaunissement des horizons inférieurs. Toutefois, ces changements de l'état structural semblent en relation avec l'excès d'humidité dans le sol (nappe peu profonde) et ne paraissent pas dus aux sels des eaux d'irrigation.

Études dans les cases lysimétriques

En 1954, nous avons repris à Rabat nos études de l'action de la salure des eaux sur les sols, mais cette fois dans des cases lysimétriques de 2 m de profondeur. Pour cette expérience nous avons choisi trois types de sols: *tirs* (sol argileux hydromorphe lourd de Sidi Slimane), sol brun des Béni Amir et *r'mel*, sol rouge lessivé sableux d'un horizon argileux de Rabat. Pour chaque type de sol, le programme prévoyait une case non irriguée, une case irriguée à l'eau douce, deux cases irriguées à l'eau saumâtre (NaCl: 1,5 g/l) avec ou sans plâtre, avec des volumes d'irrigation nécessaires pour ramener l'humidité des sols à sa capacité de rétention, dose 1, et deux cases similaires mais irriguées avec des volumes d'eau supérieurs à la capacité de rétention des sols, dose 2 (de 1 à 5 doses 1). Dans toutes ces cases, le drainage a été assuré. Cette année, nous avons mis en service deux cases supplémentaires dans lesquelles le plan d'eau (eau douce dans l'une, eau saumâtre dans l'autre) sera maintenu près de la surface du sol.

Bien que cette étude soit toujours en cours, il est possible de donner quelques renseignements relatifs à l'influence des irrigations à l'eau salée sur les rendements du coton et du maïs, cultures expérimentées dans nos cases en assolement biennal.

Les résultats de quatre années d'essais sont rassemblés dans le tableau ci-après. Contrairement à ce qu'on pourrait penser, l'irrigation à l'eau saumâtre (1,5 g/l de NaCl) n'a pas provoqué la baisse générale de rendements de ces cultures. Le coton et le maïs cultivés sur les sols bruns des Béni Amir et sur les *tirs* de Sidi Slimane, irrigués à l'eau saumâtre, accusent au contraire une augmentation sensible de la récolte, par rapport aux cases irriguées à l'eau douce, et cela pendant quatre années consécutives. L'effet positif de l'eau saumâtre était plus sensible dans les sols bruns, où les rendements ont augmenté de 20% environ, que dans les *tirs*, où l'augmentation de la récolte restait de l'ordre de 5%, sauf la première année (coton) où elle atteignait 20%. En ce qui concerne les sols sableux (*r'mel*), les résultats sont plus disparates. En effet, on observe la baisse des rendements au cours des deux premières années (1955 et 1956) et leur augmentation au cours des deux années suivantes (1957 et 1958).

TABLEAU 2. Rendements du coton et du maïs

Type de sol et désignation de la case	Coton				Maïs			
	1955		1957		1956		1958	
	Rendement	Comparaison avec case 2	Rendement	Comparaison avec case 2	Rendement	Comparaison avec case 2	Rendement	Comparaison avec case 2
	q/ha	%	q/ha	%	q/ha	%	q/ha	%
Sol brun des Béni Amir								
1 (non irriguée)	11	39	9	33	47	67	48	78
2 (eau douce)	*28*	*100*	*27*	*100*	*70*	*100*	*62*	*100*
4 (eau salée, dose 1)	30	107	38	141	90	129	72	116
3 (eau salée, dose 2)	31	111	40	148	77	110	81	131
6 (eau salée, dose 1 + gypse)	27	96	32	129	97	138	83	134
5 (eau salée, dose 2 + gypse)	30	107	46	171	79	113	74	120
Moyenne des cases irriguées à l'eau salée	29	105	39	145	86	122	78	125
"*Tirs*" *de Sidi Slimane (sol argileux lourd hydromorphe)*								
1 (non irriguée)	15	54	8	19	55	63	51	66
2 (eau douce)	*28*	*100*	*41*	*100*	*104*	*100*	*77*	*100*
3 (eau salée, dose 1)	31	115	43	105	103	99	62	80
4 (eau salée, dose 2)	39	139	34	83	100	96	82	107
5 (eau salée, dose 1 + gypse)	32	114	45	110	105	101	86	112
6 (eau salée, dose 2 + gypse)	32	114	52	127	118	113	99	129
Moyenne des cases irriguées à l'eau salée	34	120	44	106	107	102	82	107
"*R'mel*" *de Rabat (sol sableux lessivé, fortement argileux en profondeur)*								
1 (non irriguée)	18	48	9	56	18	29	16	49
2 (eau douce)	*23*	*100*	*16*	*100*	*60*	*100*	*33*	*100*
4 (eau salée, dose 1)	22	96	18	113	61	102	34	103
3 (eau salée, dose 2)	18	78	21	131	50	83	29	88
6 (eau salée, dose 1 + gypse)	20	87	25	156	50	83	37	112
5 (eau salée, dose 2 + gypse)	22	96	21	131	54	90	35	106
Moyenne des cases irriguées à l'eau salée	21	89	21	133	54	90	34	105

Il résulte de ces essais que le comportement des plantes irriguées à l'eau saumâtre dépend dans une large mesure du type pédologique du sol. En effet, dans nos essais, toutes les conditions autres que les conditions de sol étaient identiques, même climat, même plante, même technique d'irrigation. Or, l'irrigation à l'eau saumâtre qui a augmenté les rendements du coton et du maïs dans les sols bruns a eu peu d'effet dans le sol argileux lourd. Dans les sols sableux elle a même eu des effets dépressifs, au moins les deux premières années. Ce comportement des plantes paraît en relation étroite avec les caractères internes des sols.

SUMMARY

Experiments in irrigation with brackish water carried out in Morocco (Georges Bryssine)

A study of the development of soils in the Beni Amir that have been irrigated with brackish water having a NaCl content of more than 1 gm./l. and of up to 1.5 gm./l. shows that the salinity of well-drained soils in this area presents no problem for plant cultivation. On the other hand, the rise in the salt water level which results from irrigation is an important factor in raising the concentration of salts in these soils.

The presence of limestone in parts of the Beni Amir that are of a silt-clay limestone composition appears to be unfavourable to the solonetzification of the profiles, but it is to be noted that there is an increase of exchangeable magnesium in the absorbing complex of the upper horizons, probably at the expense of the lower horizons, which are rich in this element in areas where the water-table is near the surface.

Changes in the structure of the soils, which were noted as soon as water was led in, appear to be connected with excess humidity, and not to be due to the salts in the irrigating water.

Lysimeter tests have been carried out over the last four years on irrigation with salt water (1.5 gm./l. of NaCl). These tests were conducted on three types of soil—*tirs* (heavy clay soil), brown earth (silt-clay limestone) and *r'mel* (sandy soil with a clay horizon)—and the results do not show that the salts have any harmful effects on cotton and maize crops. On the contrary, in some lysimeters in which the soil was watered with salt water, yields were higher than in lysimeters watered with fresh water.

DISCUSSION

G. **Drouhin.** (1) L'eau d'arrosage des cases lysimétriques contient-elle uniquement du chlorure de sodium ou aussi un sel de calcium?

(2) A-t-on à proposer une explication de l'augmentation de rendement sur sol brun des *Béni Amir* ou sur *tirs*? Cela peut-il être dû à une amélioration de la microstructure du sol, par exemple sous l'action du calcium?

G. **Bryssine.** (1) Nous avons utilisé pour cette expérience l'eau de Rabat à laquelle on a ajouté la quantité de chlorure de sodium nécessaire pour ramener la teneur en chlorures à la concentration voulue (1,5 g/l, exprimée en NaCl).

(2) Il est difficile d'expliquer maintenant le comportement des cultures dans les sols des Béni Amir. Il s'agit probablement des processus internes de ces sols. L'état de la microstructure était satisfaisant.

G. **Aubert.** J'aimerais demander à M. Bryssine s'il connaît la teneur en potasse des divers sols utilisés dans ses expériences. Peut-être serait-il possible de chercher dans cette direction l'explication des faits assez étonnants qui nous ont été exposés?

G. **Bryssine.** Je n'ai pas entre les mains les résultats d'analyse du complexe absorbant. Si mes souvenirs sont bons, les taux du potassium échangeable varient autour de 2 à 4% de la capacité d'échange des bases.

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TRADITION ET RECHERCHE EN ITALIE DANS L'EMPLOI DES EAUX SAUMÂTRES POUR L'IRRIGATION

par

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ANCIENNES RÉALISATIONS ET INITIATIVES NOUVELLES

L'irrigation à l'eau saumâtre remonte, en Italie, à une date lointaine. Utilisée dans de nombreuses régions de la péninsule et des îles, elle est particulièrement répandue dans les Pouilles, où elle se pratique habituellement le long du littoral de la province de Bari, du fleuve Ofanto au col d'Ostuni, et dans la péninsule Salentine, dans les zones situées à l'est de la ligne Ostuni-Tarente.

Les zones des Murges, soit dans la province de Bari, soit dans la péninsule Salentine, ont une structure superficielle telle qu'elle détermine une intense et rapide absorption des eaux de pluie. Comme elles sont complètement dépourvues de cours d'eau, l'activité agricole s'y déroule soit selon des méthodes savamment choisies parmi celles qui réussissent à tirer le meilleur profit des faibles disponibilités hydriques offertes par les rares mottes de terre qui recouvrent la roche ou y sont entremêlées, soit grâce à l'utilisation des eaux salines du sous-sol.

On a pensé alors à exploiter la nappe profonde incluse dans la plate-forme calcaire de base. Comme on n'avait à ce sujet que des connaissances plutôt vagues, on sentit le besoin d'entreprendre des recherches, dont le programme et la direction furent confiés à une commission consultative composée de géologues, d'hydrologues, de chimistes, de géo-physiciens et d'ingénieurs spécialisés.

Ce fut un travail long et de grande envergure qui occupa, pendant plus de cinq ans, de nombreuses entreprises spécialisées dans les forages et exigea des sommes considérables. On creusa plus de 150 puits, dont on peut extraire une quantité d'eau estimée globalement à 7–8 m^3/s. Ces eaux, salées pour la plupart, présentent des résidus et ont une composition très variable.

La Commission a déjà préparé un rapport [4][1], tirant les conclusions du travail accompli. Ce rapport fournit d'abondants renseignements sur les disponibilités de la nappe profonde et sur la composition chimique des eaux au moment des investigations. En ce qui concerne l'extraction, il analyse avec précision les mesures à prendre afin d'éviter les dommages causés par une possible et progressive augmentation des concentrations salines relevées par les essais déjà faits; il s'en tient, en revanche, à des généralités en ce qui concerne la possibilité d'utiliser pour l'irrigation les eaux qu'on a découvertes.

CONTRIBUTIONS APPORTÉES PAR L'EXPÉRIMENTATION

A vrai dire, la commission dont il a été question plus haut n'avait pas été explicitement invitée à se prononcer sur l'utilisation agronomique des eaux souterraines; elle ne possédait pas non plus de données et d'éléments positifs et contrôlés sur lesquels on pût éventuellement fonder des évaluations.

Bordiga et Ulpiani [1] ont été les premiers à s'occuper de l'utilisation des eaux saumâtres puisées aux puits du littoral de la province de Bari. Ils ont expérimenté le comportement de quelques plants de maïs et de tomate; ils ont utilisé des eaux contenant environ 7 g/l de sels dissous, les administrant à l'état naturel ou différemment mélangées avec de l'eau potable. Leurs essais ont eu lieu pendant une année. Les résultats obtenus ont été diamétralement opposés pour les deux plantes cultivées: tandis que les productions de maïs se réduisaient d'une façon inversement proportionnelle au degré de salure, le poids des tomates augmentait considérablement en proportion directe de la concentration saline des eaux administrées jusqu'à atteindre le maximum avec les eaux les plus chargées en sels.

Passerini et Galli [8] sont revenus sur la question, puis de nouveau Passerini [7] l'a reprise, mais toujours avec des essais trop rapides et très incomplets.

Beaucoup plus intéressantes sont les observations de Pantanelli [6]: elles embrassent un vaste ensemble de faits et de circonstances contrôlés par des essais effectués dans des pots, dans des cases lysimétriques et dans des

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[1] Les chiffres entre crochets renvoient à la bibliographie en fin d'article.

champs, sur des terrains différents et sur un grand nombre d'espèces cultivées, essais répétés parfois en différents milieux climatiques, poursuivis sur des périodes généralement plus longues qu'une simple année agricole. Ce sont là des observations toujours valables et particulièrement intéressantes mais auxquelles il faut attribuer une valeur et une signification très approximatives, non seulement à cause des modestes procédés et moyens mis en œuvre, mais plus encore à cause de la faible place qu'y a tenue le facteur temps.

Le Bureau pour le développement de l'irrigation dans les régions de la Pouille et de la Lucanie [5] a commencé à s'intéresser depuis peu à cette question, employant à cet effet un champ expérimental, pour une durée de trois ans, dans le domaine d'Egnazia près de Fasano. Il a notamment étudié les différents procédés d'arrosage, l'adoption de divers rythmes d'alternance et le contrôle minutieux des quantités d'eau utilisées. Les cultures maraîchères, fourragères et industrielles ont été très variées.

Des soins particuliers ont été apportés à l'observation du degré de salure du sol pendant la durée des essais.

Tout bien considéré, le travail accompli ne paraît pas des plus satisfaisants. Il révèle des insuffisances évidentes et aboutit à des conclusions hâtives. Sans aucun doute, les nombreux faits et circonstances mis en évidence sont dignes d'attention: entre autres, les procédés d'accumulation des sels au cours de l'irrigation et leurs effets sur les activités physico-chimiques, mécaniques et microbiologiques du sol, sur les activités radiculaires des plantes cultivées et sur tous les autres facteurs qui intéressent et conditionnent la production. Mais le défaut de ces recherches réside précisément en ce qu'on n'a pas été à même de pousser l'expérimentation au-delà d'un certain temps, ce qui aurait permis sinon d'aplanir les difficultés les plus inquiétantes, du moins de supprimer les doutes les plus légitimes.

SUGGESTIONS FOURNIES PAR LA RECHERCHE

Une expérimentation plus approfondie dans le sens désiré apparaissait d'autant plus nécessaire, que les recherches — dont le but était l'étude des questions soulevées par l'emploi des eaux saumâtres pour les sols cultivés — se sont toujours révélées complexes et pleines de difficultés diverses et très graves.

Les premières complications surgissent lors de l'évaluation de la concentration saline tolérée par les plantes, et cela pour deux raisons.

En premier lieu, il faut tenir compte des modifications que subissent en terrain agricole les eaux saumâtres, notamment de l'augmentation de la salure, de l'évaporation de l'approvisionnement des cultures en eau, etc. Aussi doit-on absolument éviter de prendre pour limite de tolérance le simple taux salin de l'eau qui, au moment de l'arrosement, cause d'évidents symptômes de trouble. En réalité, la question de la limite de résistance à la salure présente des aspects et des significations tout à fait différents et beaucoup plus complexes. On ne peut ici entrer dans le détail; il suffit de s'appuyer sur des considérations simples et logiques pour acquérir aisément la conviction qu'il faudra non seulement ne pas utiliser les eaux capables de causer des troubles immédiats aux cultures, mais aussi celles qui, pour les raisons mentionnées ci-dessus, atteignent à certains moments des concentrations qui dépassent les limites de tolérance. De même, il faudra se garder d'intervenir dans des conditions où les taux salins peuvent s'additionner, ce qui provoquerait un dépassement des limites de résistance. Un autre point d'importance capitale est la nature des sels dissous. Ce problème, connu depuis plusieurs dizaines d'années, prend toute sa signification avec les observations qui ont donné naissance à la théorie des antagonismes ioniques. Par conséquent, même dans le cas des liquides circulant dans le terrain, ce n'est pas la concentration saline qui déterminera, à elle seule, le degré de tolérance des cultures: une grande partie de leur action, relative aux processus radiculaires, sera fonction des rapports entre ions dissous. Ces rapports — sodium/calcium notamment et, d'après des récentes évaluations, sodium/potassium — revêtiront par conséquent une grande importance. Pratiquement, à concentrations salines égales, la limite de tolérance constatée pour une solution de chlorure de sodium n'a plus aucune valeur pour des solutions contenant, avec le sodium, du calcium ou du potassium, ou même à la fois du calcium et du potassium. Pour ces solutions, les limites se déplacent vers des concentrations plus élevées, d'autant plus élevées que les rapports sodium/calcium/potassium le sont moins ou que l'équilibre des ions sodium/calcium et potassium est plus stable.

En outre, on doit tenir compte du terrain; car, ainsi que nous le remarquions plus haut, les cultures subissent l'influence d'eaux modifiées de différentes manières, et souvent notablement, par celui-ci.

Les lois qui règlent l'échange des cations rendent compte de l'action des eaux sur le terrain. Des renseignements suffisants sur les effets agronomiques dérivant de ces processus nous sont fournis par les connaissances ordinaires que nous avons sur le rôle des échanges de bases dans la détermination des caractéristiques de structure du sol. A cet égard, il faut insister de nouveau sur l'action bienfaisante qu'exercent les ions calcium quand ils se trouvent en compétition avec les ions sodium; d'où l'intérêt de toute pratique visant à augmenter le taux de calcium dans les liquides circulant dans le sol. Cet ion empêche en effet que le sodium ne s'installe sur la micelle argileuse; cette tâche est d'autant mieux remplie par le calcium que le rapport sodium/calcium tend à diminuer.

La recherche a établi, ou du moins laissé entrevoir, d'autres faits et circonstances en étroite relation avec l'utilisation des eaux saumâtres. Il en découlerait, par exemple, des procédés de lessivage plus efficaces ou autres que ceux des eaux pluviales ou des eaux d'irrigation normales. L'action des sels, selon leur concentration et leur nature, s'exercerait sur les populations microbiennes du sol: celles-ci subiraient des influences de natures diverses c'est-à-dire qu'il pourrait y avoir une appréciable régression ou au contraire une exaltation de leur activité.

Finalement, les avantages qui s'ensuivraient du fait que les eaux en question s'enrichiraient d'un grand nombre d'éléments de moindre importance, soit macronutritifs, soit micro-nutritifs, seraient dignes de considération. On a, en outre, une certaine confiance dans l'opinion selon laquelle le chlorure de sodium lui-même aiderait à l'amélioration des caractéristiques organoleptiques des produits d'un certain nombre d'espèces végétales, qui se sont révélées particulièrement résistantes au traitement par les eaux saumâtres.

RÉSULTATS DE L'ENQUÊTE

Ainsi que nous l'avons fait remarquer plus haut, l'expérimentation concernant l'utilisation des eaux saumâtres n'a eu jusqu'ici qu'un défaut: l'importance minime attribuée au facteur temps. Non seulement une seule année, mais même la période de trois ans qui s'est révélée nécessaire dans quelques cas, représentent un laps de temps fort modeste dans le contrôle d'une pratique pour laquelle on a prévu et même constaté de larges et profondes actions collatérales et résiduelles.

Certes, il aurait fallu pouvoir étendre les essais sur une aussi longue période que celle qui est accordée, dans différents pays, à l'étude d'autres problèmes, exigeant parfois peut-être moins de temps, et dont les résultats les plus remarquables sont ceux de la célèbre expérimentation séculaire encore en pratique à l'institut d'agronomie de Rothamsted. En Italie, aucun travail comparable n'a jamais été effectué.

Nous avons cependant fait remarquer, au début de cette communication, que les eaux saumâtres dans la région des Pouilles ont été largement utilisées depuis des siècles.

Or — et c'est là le point extrêmement curieux de la situation que nous exposons ici — les eaux saumâtres continuent à être employées par les cultivateurs de cette région à un rythme qui n'a pas changé depuis ces temps lointains. Ceux-ci emploient des procédés, évidemment liés à leur expérience séculaire, dans lesquels ils estiment avoir condensé non seulement les principes suivant lesquels sont écartés les dangers qu'ils connaissent bien et qu'ils appréhendent pour les cultures présentes, mais sans doute également les principes propres à éloigner les dommages qui se produisent à longue échéance car, depuis plusieurs dizaines d'années, aucun trouble ou désordre de quelque importance n'a été signalé. Cette singulière situation étant parvenue à notre connaissance, nous avons aussitôt vu l'importance qu'elle pourrait avoir et nous nous sommes immédiatement employés à y mettre ordre de la manière que nous avons jugée la plus convenable et la plus utile.

Les connaissances sur les concentrations salines des eaux utilisées étaient limitées et celles sur la composition des résidus salins de ces mêmes eaux à peu près nulles; la nature et les caractéristiques prédominantes des terres habituellement irriguées étaient à peu près inconnues en termes chimico-agricoles et agronomiques. Notre première préoccupation a donc été d'éclaircir ces points d'importance capitale par une série de recherches effectuées principalement sur le littoral de la province de Bari et qui ont été étendues à d'autres zones de la région des Pouilles. Plusieurs centaines d'eaux du sous-sol ont été observées et analysées dans les conditions et les localités les plus diverses. Nous ne pouvons nous arrêter comme nous le souhaiterions sur l'immense travail accompli. Nous estimons utile cependant de donner à ce sujet quelques renseignements afin qu'on puisse se former une idée des résultats obtenus et sur lesquels pourront s'appuyer les considérations que nous exposerons par la suite. Nous ferons donc mention ci-dessous des cas qui nous paraissent les plus significatifs:

1. Rivière Tara dans la province de Tarente (source);
2. Rivière Chidro dans la province de Tarente (source);
3. Rivière Idume dans la province de Lecce (embouchure);
4. Puits creusé le long du littoral de Bari (Trani);
5. Puits creusé le long du littoral de Bari (Molfetta);
6. Puits creusé le long du littoral de Bari (Monopoli);
7. Puits foré dans la péninsule Salentine (Brindisi-Serranova);
8. Puits foré dans la péninsule Salentine (Lecce-Gallipoli);
9. Puits foré dans la péninsule Salentine (Tarente-Manduria).

Les valeurs obtenues sont présentées dans le tableau 1.

TABLEAU 1. Composition de quelques eaux saumâtres de la région des Pouilles

Cas	Résidu à 110°	Cl'	$SO_4{-}'$	CO_3''	$Ca^{\cdot\cdot}$	$Mg^{\cdot\cdot}$	$K^{\cdot}$	$Na^{\cdot}$	*p*H
	g/l	g/l	g/l	g/l	g/l	g/l	g/l	g/l	
1	1,840	0,694	0,182	0,180	0,167	0,103	0,058	0,374	7,25
2	3,400	1,453	0,241	0,180	0,194	0,117	0,084	0,827	6,90
3	8,040	4,255	—	—	—	—	0,104	2,301	7,25
4	3,564	1,413	0,217	0,124	0,185	0,117	0,112	0,779	7,40
5	10,092	4,683	0,670	0,136	0,264	0,312	0,323	2,507	7,50
6	6,820	3,296	0,450	0,223	0,233	0,228	0,089	1,765	7,30
7	4,025	1,840	0,282	0,198	0,166	0,126	0,050	1,022	7,15
8	7,630	3,688	0,520	0,199	0,206	0,240	0,081	2,025	7,60
9	2,308	0,943	0,154	0,149	0,148	0,118	0,039	0,527	7,05

Les compositions observées confirment tout d'abord l'hypothèse avancée par plusieurs savants [3, 9], selon laquelle les eaux souterraines de la région des Pouilles, celles des sources comme celles des puits, doivent être considérées comme le résultat du mélange entre les eaux de terre et les eaux de mer. Ce mélange se forme suivant les rapports et les procédés les plus divers. Par conséquent, il ne faut pas considérer ces eaux comme des eaux marines qui auraient été plus ou moins délayées, et dans lesquelles l'action nuisible des sels dissous serait par conséquent plus ou moins affaiblie. Il faut, au contraire, les considérer plutôt comme des solutions ayant des caractéristiques sensiblement différentes et dont l'action — comme on peut aisément le prévoir — serait considérablement plus favorable, soit par rapport au terrain, soit par rapport aux cultures.

Donc, si l'on considère la situation des cations des eaux utilisées, on verra aisément qu'elles possèdent de grandes possibilités de formation d'antagonismes entre ions sans doute utiles. L'action du sodium est en effet puissamment contrastée d'abord par le calcium (les rapports sodium/calcium varient d'environ 2,5/1 à près de 10/1); elle est également fortement contrastée par la magnésium et, dans une mesure appréciable, même par le potassium.

Un point digne d'attention est que les eaux contenant des résidus salins supérieurs à 10 g/l ne sont ordinairement plus utilisées. Plusieurs puits sont en effet maintenus hors d'usage, et l'on a toujours constaté que le degré de salure de leur eau était supérieur à celui que nous avons mentionné; on peut prendre comme cas limite précisément celui que nous avons indiqué au n^{o} 5 (puits creusé dans la campagne de Molfetta).

TABLEAU 2. Caractéristiques agronomiques des principales formations soumises à l'irrigation

Constituants	Sables du littoral		Terres tufacées		Terres sur calcaire	
	1	2	3	4	5	6
Cailloux	—	—	—	—	—	—
Sable gros	38,40	94,21	84,87	83,90	88,04	85,61
Sable fin	50,48	1,90				
Limon	5,88	2,57				
Argile	5,24	1,32	15,13	16,10	11,96	14,39
Calcaire	22,30	17,70	42,70	45,10	12,90	18,60
Substance org.	1,42	0,54	2,59	1,22	2,01	1,76
Azote total	0,09	0,05	0,09	0,09	0,13	0,14
Anhydride phos.	0,08	0,09	0,26	0,02	0,09	0,01
Potasse	0,35	0,19	0,68	0,56	1,02	0,32
*p*H	8,05	7,75	7,60	7,30	7,55	7,65
Sels solubles	0,11	0,08	0,14	0,10	0,07	0,08

De toutes les terres analysées nous n'examinerons qu'une petite fraction indispensable pour se former une idée de leurs diverses caractéristiques et de leurs différentes aptitudes agronomiques. Nous allons considérer plus particulièrement les formations ci-après:

1. Sable du littoral Adriatique (Foggia-Siponto);
2. Sable du littoral Adriatique (Foggia-Zapponeta);
3. Terrain à sédiment marin tufacé (Brindisi-Fasano);
4. Terrain à sédiment marin tufacé (Bari-Ruvo);
5. Terrain couvrant le calcaire compact (Bari);
6. Terrain couvrant le calcaire compact (Lecce-Alessano).

Il s'agit donc de dépôts de sable généralement épais de plusieurs mètres; de légères couvertures de matériel tufacé, posées sur des bancs de roche de même nature et à partir de laquelle elles se sont graduellement formées; de couches d'une terre rouge, le plus souvent peu épaisses, étendues sur du calcaire compact abondamment lézardé. Les formations en question, qui sont perméables par suite de leur constitution mécanique, sont aussi facilement aptes à la dispersion des eaux en surplus. Ces eaux, dans les terrains sablonneux, se recueillent dans de profonds fossés de drainage, tandis que, dans les deux autres cas, elles s'éloignent à travers les roches tufacées ou calcaires sous-jacentes. Toujours riches en calcaire et fréquemment traitées avec de considérables quantités de substance organique, les trois formations en question sont en outre animées d'un considérable dynamisme par suite duquel il faut estimer que des quantités considérables de calcium restent mobilisées et que par conséquent les valeurs du sodium/calcium dans les eaux administrées avec l'irrigation diminuent de plus en plus.

Une recherche particulière a été entreprise en vue de découvrir les effets causés, dans le terrain, par des traitements prolongés à l'eau saumâtre. A cette fin, quelques dizaines d'échantillons ont été prélevés sur les terres qui, d'après les fermiers, avaient été irriguées le plus longtemps. Ils ont toujours été effectués sur des terres aménagées d'avance pour la culture irrigable: ce qui revient à dire, comme nous le verrons mieux par la suite, que ces terres avaient reçu les eaux saumâtres deux ans auparavant et qu'elles avaient bénéficié des pluies de deux périodes consécutives automne-hiver. Cette recherche portait sur l'évaluation de la quantité de sels solubles et de la composition du résidu salin et aussi sur la détermination de sa capacité d'échange et de sa composition centésimale. Bien qu'elle ne soit pas encore achevée, il serait utile de mentionner quelques valeurs précédemment acquises [2], par exemple celles qu'on trouvera au tableau 3.

Le taux des sels solubles apparaît décidément supérieur à celui des terres de la même région des Pouilles qui n'ont jamais reçu d'eaux salées, tandis que les chlorures ont tendance à se maintenir dans des limites assez modestes. Mais l'observation la plus intéressante, que permettent les chiffres du tableau 3, révèle la parfaite intégrité des terres en question.

Ce n'est pourtant qu'au terme des recherches projetées qu'on pourra se faire une idée exacte de la situation.

Toutefois, il est possible dès maintenant de souligner que si, malgré un degré aussi marqué de dessalement (tel qu'il apparaît d'après les faibles valeurs des chlorures et l'absence presque totale des sulfates solubles), les *p*H ont à peine tendance à dépasser les limites de la neutralité,

Tableau 3. Degré de salinité de quelques terres irriguées avec les eaux saumâtres[1]

	Sels solubles[1]				*p*H
	Quantité totale	Cl'	SO_4''	HCO_3'	
	g	g	g	g	
1	0,214	0,026	tr. n. d.	0,051	7,80
2	0,108	0,017	tr. n. d.	0,039	7,80
3	0,216	0,028	tr. n. d.	0,039	7,60
4	0,132	0,003	tr. n. d.	0,041	7,60
5	0,098	0,010	tr. n. d.	0,031	7,30
6	0,224	0,063	tr. n. d.	0,038	7,40
7	0,172	0,010	tr. n. d.	0,052	7,40
8	0,142	0,024	tr. n. d.	0,032	7,50
9	0,213	0,021	0,010	0,046	7,40
10	0,239	0,060	0,024	0,043	7,60

1. Exprimés en grammes par 100 grammes de terre.

cela nous autorise à exclure l'hypothèse de contaminations ou d'altérations importantes des terres. C'est précisément dans cette constatation qu'il faut voir un des résultats les plus intéressants des recherches accomplies. Ce résultat ne vaut pas seulement parce qu'il justifie les procédés suivis dans l'utilisation des eaux saumâtres, mais également parce qu'il permet de faire des prévisions sur leur application possible pendant très longtemps encore, sans qu'on ait rien à redouter.

Les procédés traditionnels, employés dans les Pouilles pour l'irrigation à l'eau saumâtre, constituent les bases fondamentales d'opérations fort logiques et convaincantes.

Pendant le cycle végétatif entier des cultures, la couche du terrain intéressée par les racines est maintenue sans cesse le plus humide possible, afin que la concentration saline des eaux employées ne subisse que des variations très faibles. Toutefois, on ne réussira pas tout à fait à empêcher une certaine accumulation de sels pendant chaque arrosage. Mais, pour l'éviter, on interviendra chaque fois avec des volumes d'eau tels qu'ils ne puissent causer dans les canaux de drainage ou dans les roches sous-jacentes que des filtrages modérés et par conséquent aptes à produire l'éloignement d'une bonne partie des sels accumulés par la couche cultivée. Après une saison d'irrigation, le champ est soumis à une culture sèche; l'irrigation est donc appliquée tous les deux ans, après dessalement du terrain par les pluies de deux périodes automne-hiver.

Afin de brosser un tableau complet des procédés employés par les cultivateurs des Pouilles dans l'utilisation des eaux saumâtres, nous devons rappeler les faits ci-dessous.

Une fois qu'on a montré que les terrains sur lesquels ces cultivateurs opèrent sont: *a*) toujours pourvus de calcaire et fréquemment approvisionnés par de considérables quantités de substances organiques, *b*) remarquablement perméables, et *c*) généralement formés de couches peu épaisses et toujours bien drainés, la méthode qui se fonde sur les trois règles fondamentales suivantes apparaît particulièrement utile et efficace: brèves rotations des cultures; emploi de volumes d'eau aptes à provoquer la percolation de la couche cultivée; arrosage du même terrain tous les deux ans. En ce qui concerne les limites de concentration des eaux utilisées, il faut remarquer qu'elles varient de 84 à 10 g/l pour la culture des tomates, de loin la plus pratiquée.

ADAPTATION POSSIBLE DES OBSERVATIONS EFFECTUÉES

Si nous allons jusqu'à considérer les conséquences extrêmes, nous en arrivons à la conclusion que, pour escompter des succès durables par l'emploi des eaux saumâtres, il est nécessaire de respecter les trois conditions suivantes: *a*) d'étroits rapports calcium/sodium devront être établis dans les eaux administrées; *b*) pendant la période d'irrigation, la concentration des eaux d'arrosage devra subir le minimum de modifications; *c*) on devra laisser le champ arrosé se dessaler de manière convenable après chaque saison d'irrigation.

Or, par suite de la nature même de ces conditions, la possibilité de diminuer le rapport sodium/calcium pourrait faire défaut soit en raison du terrain qui serait devenu dépourvu de calcaire, soit par suite du manque de matériel organique nécessaire. Il est donc évident que, dans des cas semblables, des mesures spéciales s'imposeraient telles que: fréquentes et massives administrations de marnes, ou d'autre matériel calcaire, si l'on dispose de substances organiques; au cas où celles-ci feraient défaut, on pourrait recourir à l'emploi de matières plus solubles comme le gypse.

En ce qui concerne le maintien de la concentration saline au niveau initial, des difficultés relatives au filtrage et à la dispersion des eaux filtrées pourraient être rencontrées.

Dans ce cas, il faut se souvenir qu'on peut assez facilement assurer la dispersion des eaux filtrées à travers les terrains perméables au moyen d'un réseau de canaux de drainage aussi nombreux qu'on le jugera convenable. Il reste, en revanche, le cas des terrains lourds, d'une mauvaise structure et par conséquent peu perméables, pourvus de quantités considérables de constituants chimiquement actifs et, partant, spécialement sensibles à l'action des sels, donc des terrains extrêmement difficiles pour lesquels on ne voit de meilleur parti que celui de les laisser en dehors des traitements en question, du moins jusqu'à ce qu'on ait pu améliorer de façon profonde et durable leurs caractéristiques structurales.

Les mêmes remarques sont évidemment valables en ce qui concerne la troisième des conditions envisagées, c'est-à-dire le dessalement. Ce procédé sera toujours possible pour des terrains perméables pourvu qu'ils subissent d'efficaces travaux de drainage, tandis que son action serait extrêmement lente dans les terres trop argileuses et d'une mauvaise structure, pour lesquelles au surplus les travaux de drainage imposeraient des frais particulièrement lourds.

Reste la question des limites de concentration des eaux à employer. Le chiffre 8–10 g/l que nous avons relevé pour la région des Pouilles pourra, très vraisemblablement, s'adapter à d'autres milieux climatiques et pédologiques, pourvu que les traitements soient appliqués selon les procédés indiqués ci-dessus et que la culture pratiquée soit celle des tomates. Pour d'autres cultures, on a relevé d'autres limites de tolérance aux sels: aussi, pour les eaux à utiliser, faudra-t-il songer à adopter des limites de concentration différentes de celles qui ont été relevées pour les tomates. Il est évident que ces limites devront être fixées chaque fois et pour chaque culture par des expérimentations effectuées avec soin et discernement. Ces expérimentations n'auront cependant pas besoin d'être étendues sur une durée très longue et apte à faire constater des effets à longue échéance, pourvu qu'elles soient pratiquées suivant les procédés établis, grâce auxquels les effets redoutés sont évités.

SUMMARY

Tradition and research in Italy in the use of brackish water for irrigation (O. Bottini)

Irrigation with brackish water is a method well known in Italy. It is used in several districts in the peninsula and in the islands, and is especially common in Apulia. This, therefore, is the region referred to whenever the difficult problem of the use in agriculture of water contaminated by the sea is under consideration.

This question has received careful attention in laboratory research and experimental tests. There is, however, one weakness to be noted in the work that has been done: the tests have not lasted long enough. This weakness is especially serious in the case in question, because the harm and disturbances that are most to be feared are precisely those which show up after a long period of time.

Apart from this, we have a very old tradition, undoubtedly dating back some centuries, which indicates—as it would otherwise be difficult to show—that the prolonged use of brackish water has not caused, and does not appear to be causing, conditions that might limit or compromise its use.

In short, it is recognized that the success of the traditional practice is based on a number of methods of procedure that are calculated to secure the following results: release of calcium ions from the soil and introduction of a suitable sodium/calcium balance in solutions; soil permanently moist; soil frequently watered. Good percolation is ensured by the use of amounts of water exceeding the field capacity of the layer of soil, and by good drainage arrangements.

The methods mentioned above can be successfully adapted even in areas differing from those just considered.

DISCUSSION

G. Aubert. J'aimerais demander à M. Bottini quelques renseignements supplémentaires:

(1) Quel est le *p*H de ces terres non irriguées?

(2) Quelle est la pluviométrie annuelle de la région?

(3) Quelles sont les cultures réalisées avec des eaux titrant 7 et 8 g/l?

O. Bottini. Je peux donner les précisions suivantes:

(1) Les valeurs de *p*H des terres irriguées vont généralement de 7 à 7,5.

(2) La pluviométrie annuelle de la région varie entre 400 et 600 mm.

(3) Les cultures réalisées avec des eaux titrant 6–8 g/l sont mentionnées dans le mémoire de E. Pantanelli cité dans la bibliographie [6].

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USE OF SALINE WATER FOR IRRIGATION WITH SPECIAL REFERENCE TO SALINE SOILS

by

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The irrigation waters which are classed as saline generally contain an excess of soluble salts of sodium. Taking as a basis the equilibrium equation

$$2\ \mathrm{Na} + \mathrm{Ca} - \mathrm{Clay} = \mathrm{Na} - \mathrm{Clay} - \mathrm{Na} + \mathrm{Ca}$$

Kelly, Brown and Liebig [14][1] proposed a system for evaluating the harmful effect of sodium in irrigation water and gave a ratio $\frac{\mathrm{Na}}{\mathrm{Ca} + \mathrm{Mg}}$ expressed in equivalents per million. When there is more sodium than Ca + Mg, the accumulation of sodium in the soil may be regarded as a problem. Eaton [10] used the term soluble sodium percentage found, expressed as $\frac{\mathrm{Na} \times 100}{\mathrm{Ca} + \mathrm{Mg} + \mathrm{Na}}$; values higher than 60 are considered unsafe (all concentrations expressed as milli-equivalents per litre).

The deterioration of land under irrigation is due to the increase in the ratio of sodium to calcium ions in the exchange complex. From a consideration of the reactions involved in base exchange, it seems that in the system sodium salts-calcium salts-sodium calcium clay, for every concentration of sodium ions in solution there must be a corresponding concentration of calcium ions which would prevent the sodium ions from entering the sodium-calcium clay. It follows that in such a case the presence of calcium salt in the irrigation waters would prevent alkalization of the soil. This would be of considerable importance for preventing deterioration of the land. From a further consideration of the system sodium salt-sodium calcium clay it would appear that for each ratio of sodium ions to calcium ions in the clay complex there must be an equilibrium concentration of sodium ions and calcium ions in solution. It follows from this that the question of the salt concentration permissible in irrigation waters must be related to the quality of soil to be irrigated. To express the ratio [5] of Na to other ions in the exchange complex a term DA is used which is stated as $\frac{\text{Exchangeable Na} \times 100}{\text{Total exchange capacity}}$. It goes without saying that a certain quality of water, which is capable of causing deterioration to a soil with a low degree of alkalization, may not do any further damage to a soil with a high degree of alkalization as there will be no further increase in sodium in the exchange complex.

It is therefore necessary that any standard fixed for determining the water quality should be closely related to the soil quality, and particularly to the presence of calcium salts in the soil material.

By taking into consideration the normal amount of calcium carbonate that can be expected to have been dissolved when irrigation water is applied to a soil containing calcium carbonate, we can fix the minimum concentration of sodium salt in an irrigation water which will not result in the gradual replacement of calcium by sodium. The logic of this will be apparent from the fact that most of the soil of the central portion of West Pakistan contains calcium carbonate, with which the irrigation water will become saturated as soon as it is applied to the field.

The solubility of calcium carbonate in water depends on the partial pressure of carbon dioxide in the atmosphere surrounding it. Asghar and his co-workers [4] have shown that in the absence of calcium salts the total solids in an irrigation water should not exceed 62 to 75 parts per hundred thousand of sodium chloride or sodium sulphate, or the sodium ions should not exceed 24.5 parts per hundred thousand. If, on the other hand, some calcium sulphate or calcium chloride (but not calcium carbonate) is present, then a correspondingly larger amount of sodium ions can be tolerated. The following general formula for expressing the quality of irrigation water by a concrete value has been derived by Asghar and his co-workers [4]. The value given by this formula has been designated as the salt index. All quantities in the formula refer to parts per hundred thousand.

$$\text{Salt index} = (\text{Total Na} - 24.5) - ((\text{Total Ca-Ca in CaCo}_3) \times 4.85)$$

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[1] The figures in brackets refer to the bibliography on page 266.

Magnesium may be included with calcium for the purpose of calculating the salt index. The salt index is negative for all good waters and positive for those unsuitable for irrigation purposes. The degree of badness may be reckoned as equivalent to the magnitude of the negative factor. In this way it is possible to build up a scale for irrigation waters. The salt index will vary from —24.5 to zero for all good waters and from zero up to any value for all bad waters.

Still, there is another more recent concept for the evaluation of water quality. Gapon's mass action equation formed the basis of a classification proposed by Wilcox [22] in 1948: this classification included five classes based on electric conductivity and sodium percentages. The calculation of the sodium percentage was made from the Gapon equation. Thorne and Thorne [18] modified this system, and suggested five classes for salt and five for alkalization hazard.

The law of mass action is applicable to the equilibrium reactions of soil and the Gapon equation has been found applicable to the equilibrium between sodium and calcium ions in the soil solution and the ratio of cations in the exchange complex. In 1953 the concept of the sodium adsorption ratio, based fundamentally on the Gapon equation, was given by the U.S. Salinity Laboratory [19]. This ratio is defined by the equation

$$\mathrm{SAR} = \frac{\mathrm{Na}}{\sqrt{\dfrac{\mathrm{Ca}^{++} + \mathrm{Mg}^{++}}{2}}}$$

the Na, Ca, and Mg denote the ion concentrations in milli-equivalents per litre. Based on this concept four classes of salinity and four of alkalinity or sodium hazard are established for irrigation waters. Thus water can fall into any one of the 16 different classes with low, medium, high and very high salinity or alkalinity hazards.

Eaton [10] has stressed the harmful effects that carbonates and bicarbonates may have on water quality. If calcium and magnesium are present in smaller quantities, on an equivalent basis, than the carbonates, then the excess of carbonate left after the precipitation of the calcium and the magnesium as carbonates will appear as sodium carbonate, thereby reducing soil fertility. The relationship between the presence of bicarbonates and actual alkalization has never been fully studied. Work in the U.S. Salinity Laboratory has shown that there is an increase in the exchangeable sodium percentage when there is residual sodium carbonate, which is defined as carbonate plus bicarbonate minus calcium plus magnesium, expressed in terms of milli-equivalents per litre. The effect of bicarbonates can be minimized by moderate to severe leaching of soils. Any accumulation of salts can also be checked by the carbon dioxide in the soil and produced at the plant roots. The solubility of calcium carbonate can be increased by increasing the concentration of such salts as sodium chloride and sodium sulphate. Thorne and Thorne [18] have found experimentally that carbonates and bicarbonates in irrigation waters, when applied under average field conditions, do not increase either the sodium percentages or the lime content of the soil, even when the waters are applied for long periods.

There is as yet no evidence to justify the classification of waters based on bicarbonates. When applying irrigation with waters containing residual carbonates above 2.5 equivalents per million, precautions must be taken to prevent lime accumulation and possible soil alkalization; in this respect more frequent irrigation with some leaching is helpful.

IONIC TOXICITY

Plant growth is sometimes hampered by excess or lack of certain ions. The phenomenon of stunted crop growth produced by low soil fertility is entirely different from that caused by the presence of harmful salts. Saline waters usually consist of sodium, calcium, magnesium, chloride, sulphates and bicarbonates in excess.

It has rarely been noticed that sodium salts in water cultures have caused toxic plant reactions, but Brown and others [7], as well as Ayers [6] have reported some cases of leaf injury to stone fruit trees and avocados.

High concentrations of calcium ions in saline soil solutions have different effects on different species. Wadleigh and Gauch [21] have reported that some species, like guayule, are more tolerant of added calcium salts than of other neutral salts. On the other hand, Masaewa [15] found that added calcium chloride had a more toxic effect on soil cultures of flax than added sodium chloride. It has been observed that even moderate concentrations of calcium chloride are highly toxic to stone fruits in sand culture and this is associated with the accumulation of chloride in plant leaves.

High concentrations of magnesium are generally more toxic to plants than isosmotic concentrations of other neutral salts.

High concentrations of potassium in soil solution are not generally met with, but when present they result in toxic effects. It has been reported that toxicity caused by high potassium can be diminished by high calcium concentrations.

Both Hayward *et al.* [13] and Brown *et al.* [7] have reported that chloride salts have toxic effects on peaches and other stone fruits. Other workers like Reed and Haas [17] and Cooper and Gorton [9] have reported chloride burns in the case of citrus, avocados and grape-vines.

It has been found that a number of crops are sensitive to high sulphate concentrations, because they hinder the uptake of calcium by plants, thereby increasing the absorption of sodium and potassium and upsetting the cationic balance within the plants.

The effect of bicarbonate ions on plants varies considerably with different species and in some cases results in serious injuries even at low osmotic concentrations. For example, both Wadleigh and Brown [20] and Gauch and Wadleigh [12] have reported that beans and Dallas grass are very sensitive, while Rhodes grass and beets are relatively tolerant to the bicarbonate ions. Studies have shown that bicarbonate ions affect the uptake of plant nutrients, and the nature of these effects varies with each species.

Although boron is essential for plant growth it may cause injury at concentrations slightly above the optimum, the limit of which is one part per million.

AGRICULTURAL PRACTICES AND SELECTION OF CROPS

Saline waters can be used for the successful cultivation of certain salt-resisting plants. Experiments in this connexion have been conducted in Pakistan [16] by growing tomatoes; it was observed that: (a) Sodium carbonate, in concentrations of 300 and 600 parts per million parts of water, had no marked effect on the growth of plants. (b) Sodium sulphate behaved like sodium carbonate and the plant growth was normal. (c) With sodium chloride the leaves became yellow, and with total solids equalling 750 parts per million the growth was normal whether the salts index was positive or negative. (d) Waters with total solids of 100 parts and a salt index of +6.0 to —10.0 produced some effect on the growth, which was slightly less than in the case mentioned above. (e) The plants bore no fruit. (f) In the case of water with 1,200 parts salt and a salt index of +13.0 the effect was well marked and plants developed signs of decay. (g) Water with a salt index of —12.0 had no such effect on growth. (h) In the case of water with 1,500 parts total solids and +22.0 and —19.0 salt indices, the growth was less than normal, but in case of a positive salt index the lower leaves of the plants were yellower and were decaying. (i) In cases where water contained 2,000 and 5,000 parts per million parts with salt indices —36.0 and —28.0 and +137.0 and —308.0 respectively, the plants decayed and the leaves turned yellow irrespective of the salt index.

In another set of experiments with waters having a specific conductivity of up to 3,200 micromhos/cm., no reduction in yield of wheat C591 and sugar-cane CO312 was observed on sandy loam soils.

The reclamation of saline land has been carried out successfully for the last 16 years by growing a local variety of paddy on saline soil as a reclamation crop; this method has been effective because the crop is not only salt resistant but needs standing water as well.

MANAGEMENT OF SOILS

Management of saline soils can be successfully achieved by special methods of treatment. In Pakistan it has been done by levelling the fields wherever necessary, and then beginning irrigation in about April. The water is allowed to stand 3–4 in. deep, for about two and a half months. During this period, it has been observed, the conductivity of the water standing on the field gradually falls. The field is then ploughed under proper moisture conditions and rice seedlings are transplanted in the standing water. Each week up to the end of September 3 in. of irrigation water is usually applied. The total amount of water used for leaching and for growth of one paddy crop is about 70 in. The crop is harvested in the month of October, and is followed by a predetermined rotation of crops which includes a legume to make up the deficiency in nitrogen caused by leaching.

In the Montgomery and Khanewal areas of West Pakistan there exists a 50,000-acre area of non-saline alkaline lands. These are hard, of low permeability, and difficult to bring under cultivation. Other areas in this region that are saline-alkaline respond well to the management practice for saline soils. The salines get dissolved in the irrigation water and improve the infiltration rate until such time as the salt concentrations are reduced. Although the permeability at such salt levels decreases, the soil can be improved by adopting suitable crop rotations; this helps by developing the root population. Thus the areas which are non-saline alkaline can also be improved. The standards for water quality should therefore be different for such purposes and it is possible that waters with high salt contents can be more beneficial in the initial stages of management of non-saline alkaline soils.

In the reclamation and management of saline soils with deep water tables and comparatively saline irrigation waters it has been observed that *Sesbania aculeata* and paddy can be grown with satisfactory results. However, a higher delta of water is needed, resulting in better drainage.

When dealing with areas with a shallow water-table, one has to face the problem of a soil profile of an absolutely different nature. At Chakanwali Experimental Farm [1] in West Pakistan, experiments were conducted to devise a satisfactory method for the management of waterlogged soils. The area selected was approximately 3,650 acres, most of it completely covered with water. The experimental work has shown that by maintaining a continuous flow through the soil, water with a high salt content can be used for irrigation. The flow can be achieved with the help of open drains of both the Mole and the tile variety, but our experience shows that where land costs are of no consideration open drains are most effective.

We have experience of yet another type of soil management. The area lying between the Indus and Jhelum rivers, known as Thal, is predominantly sandy, consisting of coarser material. A soil survey was carried out on an area of 2.65 million acres and it was observed that in 2.15 million acres clay content is less than 10 per cent; most of the area showed traces of colloidal matter. The climate is arid, with temperatures going as high as 120° F.; rainfall is very low. Storms carrying huge quantities of sand are very frequent.

The extraordinary soil and meteorological conditions of this tract necessitated the adoption of special irrigation

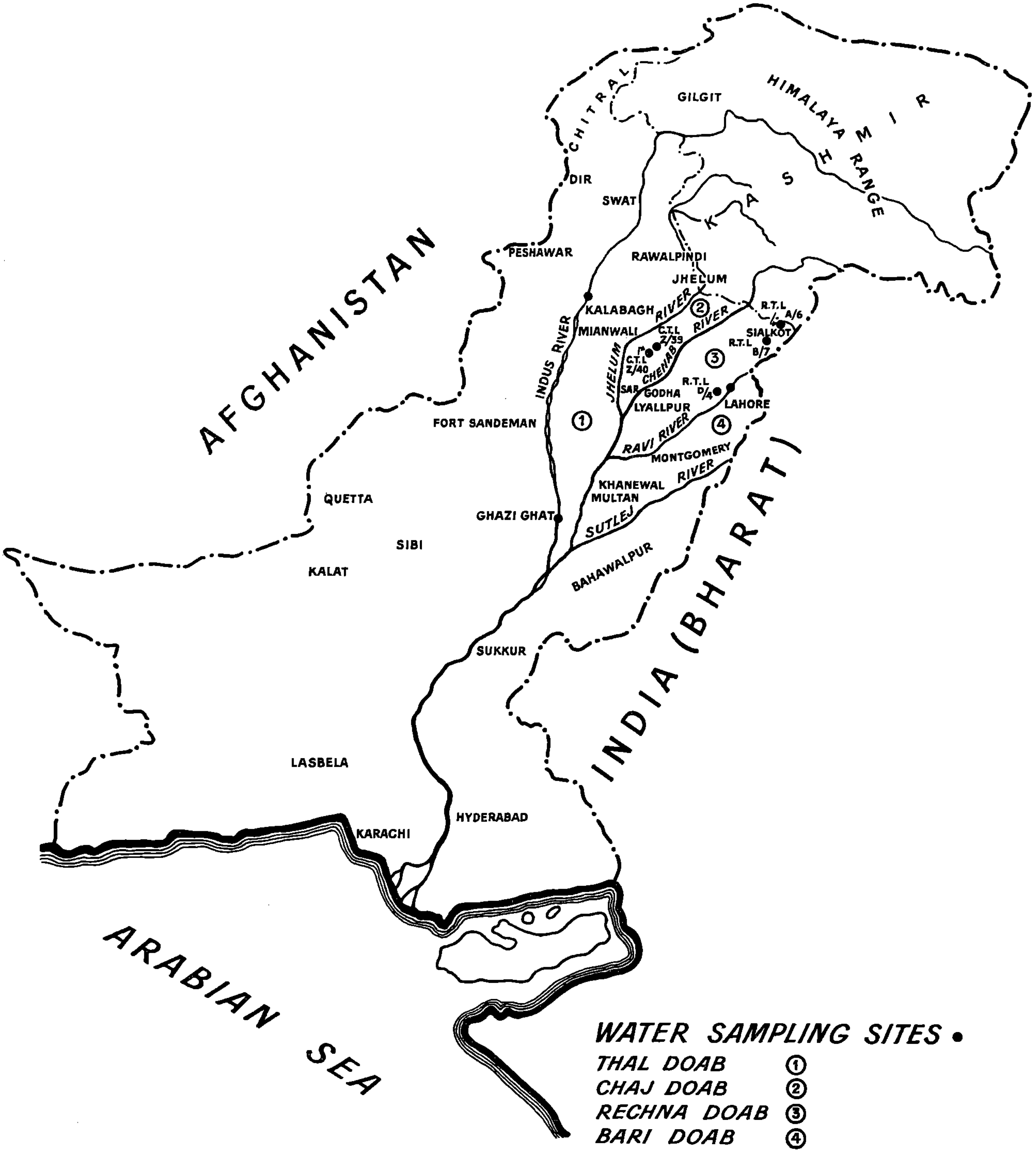

FIG. 1. West Pakistan: water sampling sites.

practices, different from those followed in other canal colonies. Generally, in the old canal colonies of West Pakistan, the water is supplied to the farmer after 10 to 15 days. These intervals of irrigation supply are not suitable for the climatic and soil conditions of the Thal tract. Even with good quality waters more frequent and heavier irrigations are required. On the other hand, when saline waters are used irrigations have to be much more frequent not only in order to maintain favourable moisture levels, but also to keep the salinity of soil solution at a level tolerated by plant roots. Since the moisture-holding properties of sandy soils are low, the ratio of the salt concentration in the soil solution to that of the irrigation waters is likely to be much higher than is usually encountered in loamy or heavier soils. This sort of situation is aggravated when the air temperatures are high, thus causing accelerated evaporation at the surface. In short, an entirely different pattern of irrigation needs to be adopted when using saline waters on sandy soils in the Thal area.

We have experience of local farmers who are following their primitive methods of irrigation from Persian wheel wells. Although some wells are yielding saline waters, they are capable of maintaining permanent cultivation. The methods adopted are such that the surface soil is disturbed to a minimum depth during ploughing, and very frequent but small irrigations are given. To maintain proper spreading of water from low heads very small plots, usually of an area of 10 ft. × 15 ft., are marked out. Thus the salts which are usually present at a depth of 3–4 ft. are not contacted, and do not move upward; consequently they are not accumulated in the top surface soil or in the root zone.

In addition to adopting different irrigation practices with different quality waters in such areas, we have to give protection to crops during growth; special techniques as well will have to be adopted to ensure the reasonable nutrient status of the soil. In Thal, sugar-cane and *Sesbania aculeata* crops are not much affected by the severity of the climate, whereas the cotton crop is badly damaged. The sand storms bury the young cotton plants and destroy them, and the scorching heat burns the young plants when the area is covered by sand particles. The high winds uproot and destroy the young seedlings. If in particular years the plants mature, the crop yield is adversely affected by the shedding of flowers, owing to the high wind velocity. Experiments [2] conducted in this connexion resulted in a new lay-out and a revised procedure for growing cotton. It has also been suggested that for the protection of cotton crops from frequent and severe sand storms the use of wind breaks should be resorted to.

It is thus evident that the same quality of water will have to be used under different irrigation-agricultural practices, depending upon the soil type. We have studied our soils in accordance with U.S.D.A. soil survey standards, and have classified them into various series.

SOIL CLASSIFICATION

The following soil series have generally been recognized during the soil survey in West Pakistan: *Jhang* soil series; *Farida* soil series; *Buchiana* soil series; *Chuharkana* soil series; *Nokhar* soil series.

Jhang soil series

These are sandy textured soils, varying from *Jhang* sand with 90 per cent sand to *Jhang* sandy loam with an average of about 70 per cent sand. These soils are porous and very permeable and have a low water-holding capacity. The permeability is greater than 2 in./hr.

Farida soil series

These soils are moderately coarse-textured. Fine sandy loam and sandy loam are found to exist in the subsoil down to a depth of 72 in. The substratum varies from loose sand to clay. The colour of these soils varies from light greyish-brown to greyish-brown. Occasionally a lime concretion zone is met within the profile, at depths varying from 5–7 ft. These soils are of moderate rapid permeability, 1–2 in./hr., have good water-holding capacity, and have good drainage characteristics.

Buchiana soil series

The *Buchiana* soils are medium-textured with soft and relatively porous subsoils. The surface varies from sand to silt loam with loam as the dominant texture. They have a favourable water-holding capacity. The colour is brown with a slight reddish, green or yellowish coloration near the ground-water level. They are calcareous throughout the soil profile and may have a zone of lime accumulation. The permeability is 0.5–1 in./hr.

Chuharkana soil series

These soils are medium-textured and have poor internal drainage throughout the profile. The surface texture varies from loamy sand to clay loam and the subsoil from clay loam to silty clay loam. They are very slowly permeable and are of fairly high bulk density; their water-holding capacity is also fairly high. The permeability is 0.1–0.5 in./hr.

Nokhar soil series

The surface soil ranges from loam to clay loam and the subsoil layers from a clay loam to clay texture. At the time of the survey these soils commonly had a perched water table close to the surface. The real water was usually much deeper and was held down under pressure by the light clay subsoil. When saline these soils are very difficult to reclaim, and are potentially inferior. The permeability is less than 0.1 in./hr.

The management of soils of different series will have to be undertaken with the permeability factor in view. The saline waters may produce different results in different cases. Soils with low permeability, viz. the *Nokhar* series, respond well to some saline waters, and salt-resistant grasses may be grown. On the other hand the light soils of the *Jhang* series would need larger quantities of irrigation water depending upon the saline content, so that a good amount of drainage must be allowed to prevent the accumulation of salts in the soil. Soils of high permeability are easier to manage, when using water of lower quality, than clayey impermeable soils.

Owing to semi-arid climatic conditions there is more evaporation from the soil surface than downward movement of moisture. The rainfall and the irrigation waters used for growing crops do not sufficiently help to counterbalance the upward movement of moisture and, instead, while moving upward, dissolve the salts present at various depths, that are left at the soil surface on evaporation. The accumulation of salts at the surface is, therefore, accelerated by insufficient rainfall-cum-irrigation. Asghar and Hamid [3] suggest a treatment for keeping the salts depressed and promoting their tendency to move in the downward direction. They have recommended the growing of sugar-cane or cotton under a slightly higher delta of irrigation on saline and partially saline soils.

LAND DRAINAGE

Asghar and Hamid [3] have observed that reasonable progress in reclamation can only be achieved when sufficient water is made available. The applicability of this technique is for the prevention of upward salt movements in the reclaimed soils as well as for those soils in which the state of deterioration is such that the salts are beyond the root zone of the crops. It is envisaged that the salts can be kept depressed for a long time and normal cropping can be carried out economically. If saline water is used, then the quantities required are considerably higher. The higher the salinity of the water, the greater would be the volume used for irrigation to keep the salt accumulation at a minimum level, as extra quantities of irrigation water would have to pass through the soil profile.

Crop production is reduced when the salt concentration of the soil solution attains an undesirable level. Sometimes the concentration is as high as ten times the concentration of salts *in* water resulting from evaporation and the dissolution of salts already present in the soil. This indirect but undesirable effect of irrigation water can be prevented by allowing some irrigation water to pass through the root zone so that the salinity of the soil solution can be kept at a desired and favourable level. The U.S. Salinity Laboratory [19] has given a formula for the leaching requirements:

$$\frac{D_{dw}}{D_{iw}} = \frac{EC_{iw}}{EC_{dw}}$$

where the leaching requirement is expressed as the percentage or fraction of the water applied that must leach through the soil. D_{iw} is the depth of irrigation water applied in inches; D_{dw} is the depth, in inches, of drainage water leaving the soil; EC_{iw} is the electrical conductivity of the irrigation water; and EC_{dw} is the average electrical conductivity of the drainage water leaving the bottom of the root zone. EC_{iw} and EC_{dw} must be expressed in the same units. In applying the equation, a value is usually assumed for EC_{dw} to represent the maximum soil salinity that can be tolerated.

If an irrigation water has a conductivity of 4,000 micromhos and the maximum concentration of salts considered permissible in the soil solution is 4 millimhos, then the leaching requirement would be $4/4 \times 100 = 100$ per cent. Hence, if an application of 4 in. of water is required to replenish the soil moisture, a total of 8 in. of water would be needed for proper leaching. The leaching requirements for saline waters are usually high.

The irrigation practices followed in West Pakistan in the past with very good waters have produced the present-day deterioration mainly because of the high water duty and the absence of proper drainage. The economical use of water has really been the cause of salinity, whereas a higher delta of irrigation with proper drainage would have been more beneficial.

In irrigation farming the practices that are followed for irrigation play an important role in assessing the efficient use of the water. It has been observed that, owing to the inefficient grading of fields and low head of water, losses do take place which are added to the subsoil without improving the salt balance in the root zone of the soil. It has been observed that even in average conditions a part of the irrigation water percolates into the subsoil, where water just enters the basin and does not affect any leaching of salts in the rest of the field. It is, therefore, necessary that saline waters should only be used on well levelled land and with an optimum head of water for quick and uniform distribution all over the field.

Eaton [11] has given some formulae which can be helpful in assessing the amount of drainage needed when using different qualities of irrigation water. The salinity status of the soil solution is maintained at a level at which 70–80 per cent of the crop yield can be obtained. Required drainage (tentative) can be calculated keeping in view the original salinity of the irrigation water, while drainage (final) can be ascertained by including the calcium content of the water. The two formulae are

$$\frac{S_w \times 100}{2 \times M_{ss} - S_w} = \%\ \text{drainage (tentative)}$$

and

$$\frac{S_w - \frac{1}{2}\ \text{total Ca}}{2 \times M_{ss} - (S_w - \frac{1}{2}\ \text{total Ca})} = \text{drainage (final)}$$

where S_w is meq./l. of Cl + ½ SO_4, and M_{ss} is the mean salinity of the soil solution.

The basic principle of these formulae is that where irrigation waters of higher saline content are used higher drainage has to be provided to maintain a normal yield of crop. The drainage requirement would be even higher for more saline waters. No basic work has been reported that might throw light on the utility of the above-mentioned concepts, yet the trend of thought they represent is practically sound and presents good scope for research.

WATER TREATMENT

The shortage of irrigation water in Pakistan and the limited range of chemical qualities it offers has left no alternative for the farmer but to use the water available. If water of low quality is to be used measures to improve its quality must be adopted. Waters having high sodium percentages but relatively low total salts have an alkalizing effect on the soil. The quality of such waters can be improved by increasing their calcium content. This can be achieved by treating such waters with gypsum-commercial calcium sulphate.

TABLE 1. Showing the replacement of Ca by NaCl solution in the presence of increasing amounts of Ca ions (exchangeable Na/100 gm. of soil)

Concentration NaCl	Nil	Saturated with $CaCO_3$	$CaSO_4$ 25% saturation	$CaSO_4$ 50% saturation	$CaSO_4$ 75% saturation	$CaSO_4$ saturated
%						
0.000	1.100	—	—	—	—	—
0.025	3.100	2.80	—	—	—	—
0.050	6.620	7.12	0.82	0.50	0.80	—
0.075	9.080	8.45	2.57	1.14	1.70	—
0.100	11.250	12.15	3.31	1.61	2.00	0.38
0.150	15.840	15.15	6.52	2.51	4.01	—
0.200	19.950	19.29	9.85	6.82	5.11	1.14
0.250	24.360	22.82	11.59	9.13	7.42	1.14
0.300	25.720	25.70	11.98	13.57	8.93	1.52
0.400	—	—	17.61	14.57	11.88	3.43
0.500	—	—	18.33	—	14.94	6.63
0.600	—	—	23.50	—	17.90	8.50
0.700	—	—	25.68	—	18.10	11.50
0.800	—	—	—	—	21.45	13.50
0.900	—	—	—	—	—	15.55
1.000	—	—	—	—	25.65	16.47

TABLE 2. Showing the replacement of Na ions by Ca from a composite sample of alkali soils by leaching with NaCl solution containing different amounts of calcium sulphate

Concentration of NaCl	Exchangeable Na – meq./100 gm. soil			
	$CaSO_4$ 25% saturation	$CaSO_4$ 50% saturation	$CaSO_4$ 75% saturation	$CaSO_4$ 100% saturation
%				
0.10	1.00	0.50	0.20	0.40
0.20	3.30	1.10	0.20	0.30
0.30	5.30	1.40	0.80	0.30
0.40	4.50	2.40	1.00	0.50
0.50	5.30	2.20	2.00	0.90
0.60	7.60	3.20	1.90	2.00
0.70	6.95	2.60	—	1.80
0.80	6.76	3.40	2.50	1.60
0.90	7.30	3.60	2.80	2.00
1.00	9.00	—	3.40	2.80

Asghar, Puri and Taylor [4] studied in detail the influence exerted by the presence of calcium sulphate in varying concentration on the replacement of calcium or sodium ions from the soil exchange complex. Tables 1 and 2 give the replacement of calcium and sodium respectively. These results are of great practical significance. The use of calcium sulphate can make it possible to keep soils under permanent cultivation with saline waters. Gypsum can be spread on soils and hitherto bad waters can safely be used for producing normal crops. The use of gypsum on soils is suggested because a farmer, even one in a backward country who is unaware of mechanical methods, can broadcast the chemical and is not confronted with the problems of using mechanical devices to mix gypsum in irrigation waters.

Low quality waters can be improved by being mixed with good quality waters. In West Pakistan this is possible by mixing canal waters which are of excellent quality with inferior quality water from other sources. The ratio of the two waters is not usually higher than 1 : 1; this is necessary because of the limited size of the water ditches, which have a capacity of 2–3 cu.ft./sec. If the lowest discharge from a well, which is 1.5 cusecs, is taken into consideration, then the ratio of mixing has to be 1 : 1 vis-à-vis the capacity of the water course.

RÉSUMÉ

Utilisation de l'eau saumâtre pour l'irrigation, notamment dans les régions à sol salin du Pakistan-Oriental
(A. G. Asghar)

L'auteur expose diverses méthodes de classification des eaux, et étudie les modalités de l'emploi de différentes catégories d'eau pour l'irrigation. On peut se servir d'eaux fortement salines à condition que le sol soit perméable et bien drainé, et qu'on apporte un excès d'eau pour lessiver le terrain.

Les effets toxiques des divers ions sur la croissance des plantes sont décrits. La présence d'une forte quantité de sodium dans le complexe d'échange du sol entraîne une dispersion plus marquée dans les sols à texture fine. Un compte rendu des expériences effectuées par l'Organisation de recherche du Pakistan est donné. L'auteur traite du choix des espèces à cultiver et des techniques d'aménagement du sol qui permettent d'obtenir des rendements satisfaisants en employant des eaux d'irrigation fortement minéralisées. Il indique quelles techniques on utilise dans le Pakistan-Oriental pour amender les sols salins et cultiver le coton et la canne à sucre sur les terres partiellement salines de la partie haute du Delta.

Enfin il fournit des précisions sur les moyens d'améliorer la qualité de l'eau, sur la tolérance aux sels des diverses cultures, sur la disposition la plus rationnelle des canaux d'irrigation et sur les résultats d'analyses des eaux de diverses catégories.

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USE OF BRACKISH WATER FOR IRRIGATION AND ITS EFFECTS ON SOILS AND CROPS

by

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One of the major sources of irrigation water is constituted by subsoil waters from: (a) drains; (b) wells; (c) tube wells. Each of these contains saline waters; they are studied in turn below.

Drains. In order to reclaim damaged areas under the Deccan canals, drains are opened to lower the subsoil water-level in the damaged areas and to facilitate the carrying on of further reclamation operations. Waters flowing through these drains are available for irrigation. These waters, being mostly from the subsoil with a zone of accumulation of salts, are saline, and prove to be injurious if used for irrigation.

Wells. Open wells, mostly in the deep soil areas, draw subsoil waters through the zone of accumulation of salts and are saline.

Tube wells. Waters from tube wells from Gujrath are highly saline; consequently, a serious problem arises in connexion with their use on lands.

Waters from sources "wells" and "tube-wells" mentioned above become more saline in hot weather, when they are in high demand. The range of salinity of waters from each of the above sources is given in Tables 1 and 2.

LIMITS OF SALT CONTENTS AND *p*H VALUES IN RELATION TO CROP GROWTH

As a result of earlier experiments, the limits of salinity in relation to plant growth were fixed as shown in Table 3.

These limits were further confirmed by growing cultivated crops with waters of varying salinity; the results are as shown in Table 4.

The salinity of waters available from drains and wells is indicated in fig. 1.

TABLE 1. Results of analysis of drainage waters under different canals in the Bombay Deccan

Name of *drainage scheme*	Drain no.	Survey no.	Village	Total salts in parts per 100,000	*p*H value
Godavari canals					
Kopargaon	3 HWF	—	—	150.0	9.24
	P.L. no.3	—	—	165.0	8.30
Girna Canal	2	—	Adhar	100.0	8.00
Takli Brahmangaon	4/1	Ch. 200′	—	110.0	6.64
Khirdi	7/1	Ch. 200′	—	105.0	9.08
Chas	—	87	Velpur	100.0	7.90
Pravara canals					
Matapur	—	67	Matapur	100.0	6.60
Kolhar Bhagavatipur	3	134	Padhegaon	102.5	8.64
	2	92	Bhagavatipur	100.0	7.20
		95	Bhagavatipur	130.0	—
Deolali	—	339	Deolali	120.0	9.00
Malemuthe Vadgaon	3/1	207	Vadgaon	600.0	6.68

CONTRIBUTION OF SALTS TO SOILS DUE TO USE OF SALINE WATERS FOR IRRIGATION

The suitability of waters for irrigation under the conditions obtaining in the Bombay Deccan was examined long ago, a general limit of salts of 100 parts per 100,000 having been fixed as suitable for irrigation. Perennial crops like sugar-cane, plantains, lucerne and other grasses take irrigation water in excess of 100 in. during the year. The quantity of salts added to the soil therefore works out to

$$\frac{100 \times 101 \text{ (tons of water)} \times 0.1 \text{ (per acre inch)}}{100} = 10.1 \text{ tons}$$

TABLE 2. The chemical composition of some tube-well waters, from North Gujrath, having total salt contents above 150 parts[1]

	Radhanpur		Chansama Tharad	Viramgaon		Dholka Koshindra	205′	Deodar 230′	274′	Chetral	Vadav Swami	Jalusan
	Munjpur	Bosfa		Detroj	Viramgaon							
Dissolved salts	351.0	216.80	216.00	162.00	272.00	311.40	1076.0	180.00	183.00	179.00	175.00	202.00
$CaCO_3$	—	—	—	9.97	11.34	—	48.0	26.07	25.02	19.00	19.00	43.01
$CaHCO_3$	—	18.49	8.42	—	—	20.10	—	—	—	—	—	—
$CaSO_4$	52.14	—	—	21.39	—	—	—	—	—	—	—	—
$CaCl_2$	—	—	—	—	—	—	—	—	—	—	—	—
$MgCO_3$	—	—	—	—	17.32	—	19.21	9.65	8.93	12.84	10.42	5.01
$MgHCO_3$	—	7.04	28.70	—	—	73.56	—	—	—	—	—	—
$MgSO_4$	25.25	2.65	—	6.81	20.85	—	81.60	—	—	—	—	16.13
$MgCl_2$	—	—	—	11.58	—	—	—	—	—	—	—	—
Na_2CO_3	—	—	—	2.11	16.90	—	—	—	—	—	—	—
$NaHCO_3$	—	—	18.71	—	—	9.24	—	31.06	5.48	46.60	46.43	—
Na_2SO_4	111.30	30.59	25.75	—	0.38	90.80	34.47	10.83	15.58	10.72	11.05	4.59
NaCl	159.20	160.00	140.00	99.77	198.00	119.10	858.60	102.00	125.40	100.90	98.80	127.30
*p*H	5.00	7.50	8.50	8.30	9.00	8.30	8.00	7.70	7.70	8.00	8.80	8.25

[1] Results, except *p*H, are expressed as parts per 100,000 parts.

TABLE 3

Salt content (parts per 100,000)	Suitable	Doubtful or unsuitable
Up to 40 parts	All waters generally fit for irrigation	
41–60	$pH < 9.0$	$pH > 9.0$
61–80	$pH < 8.5$	$pH > 8.5$
81–100	$pH < 8.0$	$pH > 8.0$
101–120	Doubtful. *p*H deceptive	
121 or more	Generally unfit for irrigation	

TABLE 4

Salt content	*p*H value	Crop condition
126	8.78	Crop of lucerne failed
108	8.52	Crop of sugar-cane failed
119	8.00	Poor crops of sugar-cane and lucerne
196	8.64	Crops of bringjals and lucerne failed
51	9.5	Crop failed

Generally 30 per cent of the total water added is retained in the soil and the salts dissolved therein are added to the soil. This amount of salt is generally distributed over a one-foot layer of soil and the addition to the salt content of that layer of soil will be of the following order:

$$\frac{0.3 \times 10.1}{12 \text{ in.} \times 150 \text{ tons per inch of soil per acre}} = \frac{3.03}{1800} =$$

$$= 0.18 \text{ per cent}$$

Where the quantities of water applied exceed 100 in., the percentage increase in salts will be proportionately more.

SUGAR-CANE

Salt-resistant varieties of sugar-cane were tried in the experimental area with soils of varying salt content. The varieties were randomized in three blocks. Water levels in this area were between 2–3 ft. at the time of plantation. The salt content at the surface varied up to 1.5 per cent. Water levels were lowered by an open drain.

The yields obtained from different varieties of sugar-cane in relation to varying soil salt contents were as shown in Table 5 and in fig. 2.

A thick incrustation of salts appeared at the surface where the sugar-cane varieties mentioned above were tried.

In areas where the salt content was in excess of 1.5 per cent at the surface it was difficult to obtain the proper germination of the sugar-cane. With more than 2.5 per cent salt in the surface (1 ft. layer of soil) germination was very doubtful. A method of growing sugar-cane in

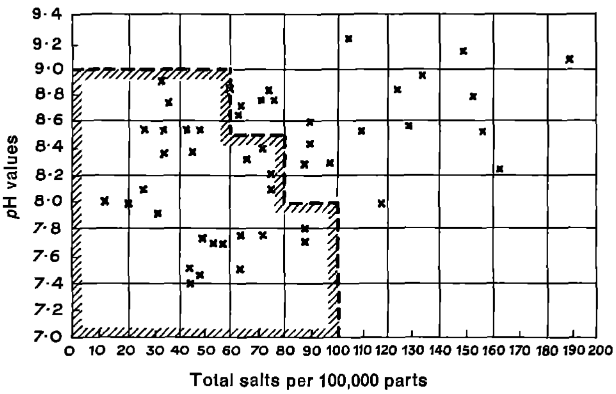

FIG. 1. Salinity and alkalinity of drain waters. (Samples within shaded portion are suitable for irrigation.)

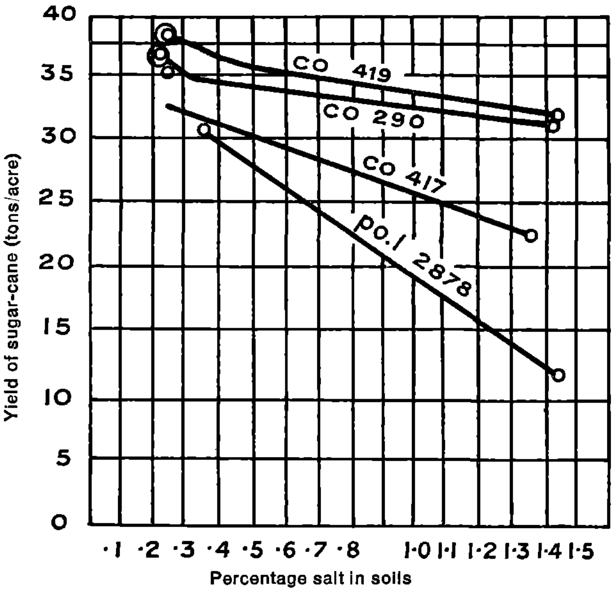

FIG. 2. Tonnage of cane per acre obtained from different varieties of sugar-cane with varying salt content in soils.

less saline soils and then transferring the complete stools after 4 months was tried in such cases; in this way the sugar-cane crop was established.

The percentage of survival of the transplanted cane crop is given in Table 6.

The transplanting of the cane crop at the age of 4 months in the monsoon season could be done with a salt content of up to 3.7 per cent. The resultant product, namely *gul* (raw sugar), contained more salts.

DHAINCHA (*Susbania aculeata*)

This is a green manuring crop which tolerates a certain amount of salt content in soils. The yields of this crop fall considerably when the salts in the soil surface (depth 1 ft.) exceed 1.0 per cent. The yields obtained with varying salt contents were as shown in Table 7.

Of the various green manuring crops this crop alone thrives better under saline soil conditions.

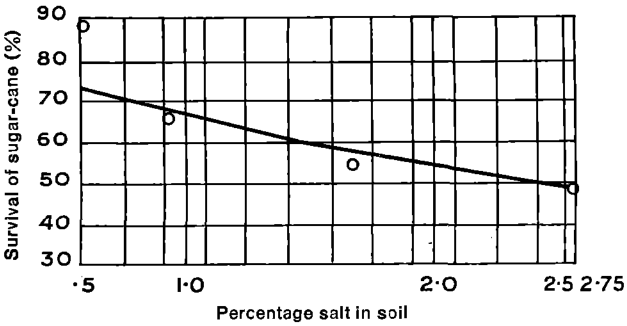

FIG. 3. Percentage survival of sugar-cane with varying salt content in soils.

TABLE 5

Variety	Salt content	Yield per acre in tons
	%	
POJ. 2878	0.35	30.2
	1.43	12.0
Co. 290	0.24	35.2
	0.22	36.5
	1.42	31.5
Co. 417	0.27	32.5
	1.34	22.7
Co. 419	0.28	37.9
	0.51	35.5

TABLE 6

Salt content	Percentage survival of transplanted cane
%	
0.5	89.0
0.9	66.0
1.75	53.0
2.75	46.0

TABLE 7

Salt content	Green weight of Dhaincha crop per acre
%	lb.
0.5	40 397
0.7	35 840
0.9	15 360
1.5	8 960
3.0	5 120

BARBADA (*Indigo-fera trifoliata*)

This is a wild plant, producing a large number of nitrogenous root nodules. It was tried in the saline areas. Green weight was recorded for various salt contents in soils at the time of harvest (see Table 8).

TABLE 8

Salt content	Green weight of Barbada per acre
%	lb.
0.42	23 680
0.50	9 600
1.25	Failed
2.25	Failed

It is evident from the above that this plant was not suitable for saline soils.

It will thus be seen that a sturdy crop like sugar-cane could be established with up to 1.5 per cent salts in the soil if the requisite changes were made in the cultural operations and planting time, and suitable, resistant varieties adopted.

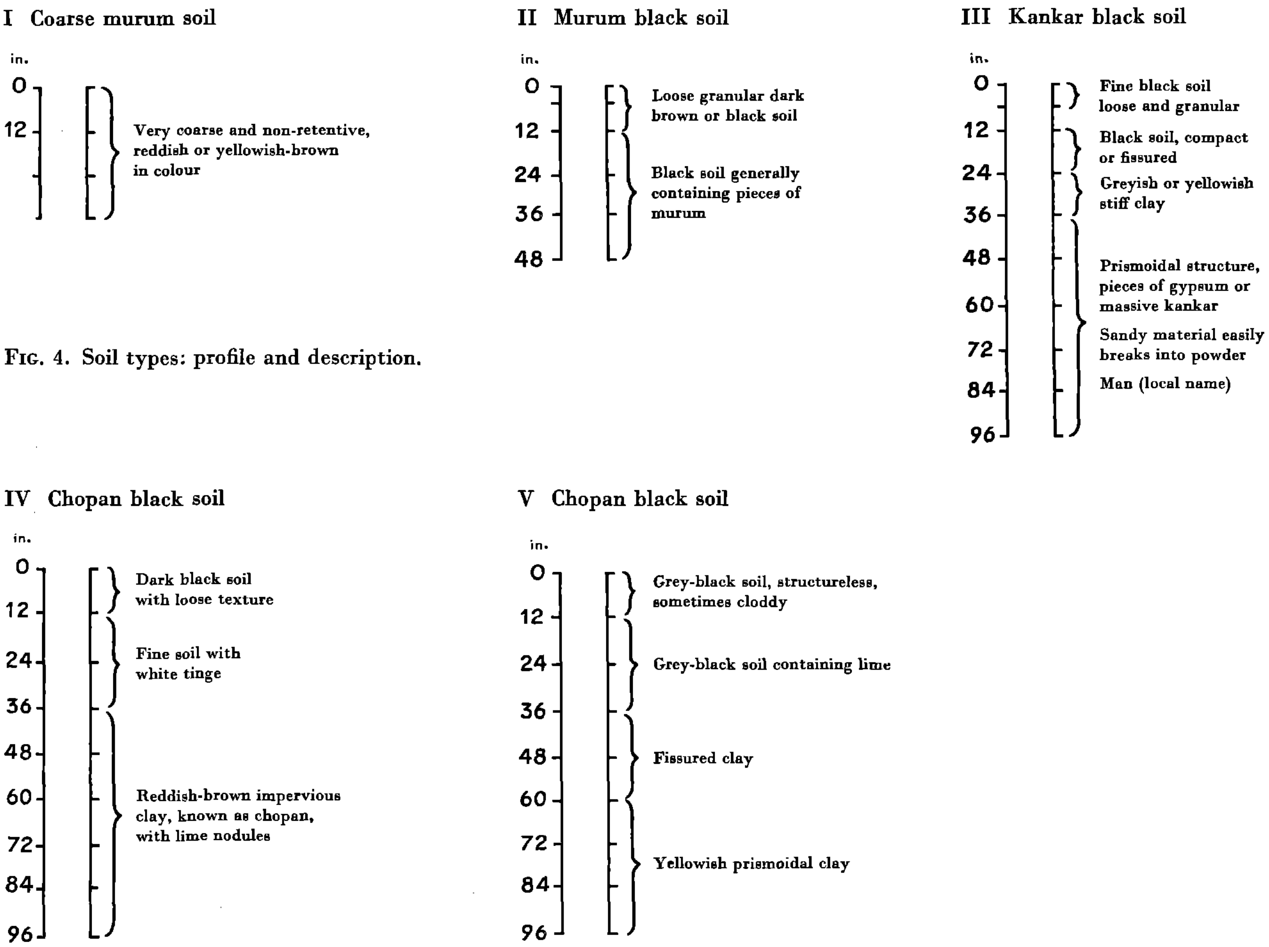

FIG. 4. Soil types: profile and description.

The sugar-cane crop is generally grown on soils with a soil column of from 1½ ft. to 8 ft., as shown in fig. 4; the salts added by means of saline waters get deposited into the soil and come up to the surface with evaporation. In order to prevent this further addition of salts to the soil, the imposition of a limit of 100 parts of dissolved salts per 100,000 parts of irrigation water works well.

We turn now to the problem of the use of saline waters from tube-wells in Gujrath.

THE PROBLEM OF THE USE OF SALINE WATER FROM TUBE-WELLS IN NORTH GUJRATH

The North Gujrath comprises the four districts of Banaskantha, Sabarkantha, Mehsana and Ahmedabad. A major part of the tract is covered by alluvium and sub-alluvial deposits which rest upon a basement of rock formations such as the Tertiary rocks, Deccan trap and pre-Cambrian schist and gneiss. The basement rocks slope down irregularly towards the south-west, in which direction the alluvium becomes thicker.

The chief factor against using the underground waters in this tract freely is their saline content. A study was therefore undertaken to ascertain the quality of the waters in order to determine their suitability for irrigation. Samples, from the existing artesian and sub-artesian bores, were collected from parts of North Gujrath.

The chief object was to study whether the water with a high sodium chloride content would be suitable for irrigation. For purposes of convenience, the tract was divided into four areas having some topographical similarity. These are the Radhanpur, Chanasma, Viramgaon and Dholka areas.

The chemical composition of some water samples from the tube wells is given in Table 2.

What is required is a solution to the problem of using saline waters with a salt content in excess of 300 parts per 100,000 on tracts covered by alluvial and sub-alluvial deposits. As shown in Table 2, there are also cases where the total salts in the tube-well waters are in excess of 1,000 parts per 100,000 and the sodium chloride exceeds 80 per cent of the total salts present.

RÉSUMÉ

Utilisation des eaux salines pour l'irrigation
(D. G. Kulkarni)

Ce document décrit les travaux préliminaires effectués en vue de déterminer les eaux qui conviennent à l'irrigation.

Les eaux extraites du sous-sol et les eaux des puits ont un degré de minéralisation plus élevé et l'on risque, en les employant, de saliniser et d'alcaliniser les terres.

Pour déterminer la possibilité d'utiliser l'eau à des fins d'irrigation, on a coutume de se fonder uniquement sur l'analyse chimique et le degré de salinité; mais il importe de souligner que cette façon unilatérale d'aborder le problème n'est pas entièrement satisfaisante. Elle peut avoir pour effet d'empêcher de larges fractions de la collectivité de tirer parti des ressources locales en eau.

Diverses expériences ont montré qu'il importe, en pareil cas, de tenir compte aussi de la nature des sols à irriguer et des cultures qu'on se propose d'y pratiquer.

Le document indique les degrés de tolérance au sel de diverses plantes, et les méthodes qui permettent d'obtenir des récoltes normales dans de semblables conditions.

Cependant le problème a un caractère complexe, et on ne peut préconiser l'utilisation d'eaux salines qu'après avoir étudié l'origine des sols, la répartition des sels dans le profil et la capacité de drainage de la région considérée.

DISCUSSION

G. AUBERT. Le D^r^ Kulkarni peut-il nous indiquer sur quel type de sol (en particulier texture) les expériences rapportées dans cette communication ont été réalisées?

D. G. KULKARNI. It refers to loamy and clayey soils.

A SUMMARY OF THE REPORT ON LEACHING EXPERIMENTS IN THE KARKHEH AREA, KHUZISTAN, IRAN

by

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INTRODUCTION AND OBJECTIVES

Salinity both in soils and in waters in Iran is one of the major problems for their effective utilization in agriculture. There seems to be some relationship observed between salinity of soil and of water. No comprehensive study has been made on the extent of salinity in soils and in waters, though considerable data is being accumulated on the subject. A generalized soil salinity map of a 3-million hectare plain of Khuzistan in south-west Iran was prepared as part of a soil survey and other development studies of this area. This indicates (fig. 1) that considerable areas of the southern Khuzistan plains are severely saline. Some irrigation projects, like the Karkheh project, have been and are being developed.

To establish permanent agriculture on some of the saline soils in the Karkheh project area of Khuzistan, a co-ordinated reclamation programme is essential. Leaching, drainage and other ameliorative measures have therefore to be considered as a whole. Leaching alone without adequate drainage, either natural and/or artificial, may prove detrimental rather than beneficial. Even after leaching has produced favourable results, it must be followed up by sound methods of irrigation; soil and water management are the key to sustained irrigated farming on these newly reclaimed lands.

No data exist regarding the leaching and drainage properties of these soils. A preliminary plot experiment was, therefore, conducted in the summer of 1955. For the saline soils on which the experiment was carried out most layers of the soil profile had heavy to very heavy texture. Leaching by increasing amounts of water decreased the salt content of the soil horizons, whose depths increased roughly in proportion to the quantity of water applied. The maximum quantity of water applied, i.e. 120 cm. in 8 irrigations, was able to leach most of the salt from about 100–130 cm. depth of soil. The depth to ground-water varied very little, even taking seasonal fluctuations into consideration. It remained below 4 m.

Two further plot experiments were conducted in the spring and winter of 1956. The object was to accumulate further knowledge on the leaching properties of soils with layers of varying textures, and especially: (a) to determine the requirements of water for leaching of soils with varying degrees of salinity when leaching is to be obtained at varying depths of soil; (b) to study the permeability of the profile and its changes, if any, during and after the experiment; (c) to study the natural drainage of the area, and the rate of rise of ground-water.

ORGANIZATION OF EXPERIMENTS

The first experiment (KL1) involved 16 plots, each 10 × 15 m.; four treatments were made, i.e. checking, 30 cm. water, 60 cm. water and 120 cm. water. However, for the next two experiments (KL2 and KL3) 20 plots, each 10 × 15 m., were laid down in four replicates of the following five treatments:

1. No leaching.
2. Four times 12.5 cm. water: 50 cm.
3. Eight times 12.5 cm. water: 100 cm.
4. Twelve times 12.5 cm. water: 150 cm.
5. Sixteen times 12.5 cm. water: 200 cm.

Each treatment was randomized, the plot arranged in two strips separated from each other by a canal system.

Soil samples were taken from each plot before the start of the experiment, and their total soluble salts (T.S.S.) determined by means of a conductivity bridge. Samples were taken from each of the following layers: 0–10 cm., 10–40, 40–70, 70–100, 100–130, 130–160, 160–190, 190–220, 220–250 and in many cases at 30 cm. intervals up to a 370 cm. layer.

Observations on depth to ground-water were made from the two holes drilled just outside the plots; the depth was ascertained at the start of the experiment and after each 50 cm. irrigation. Check wells were placed at some distance from the experimental site in order to assess the seasonal fluctuations of ground-water. The quality of ground-water was also ascertained before,

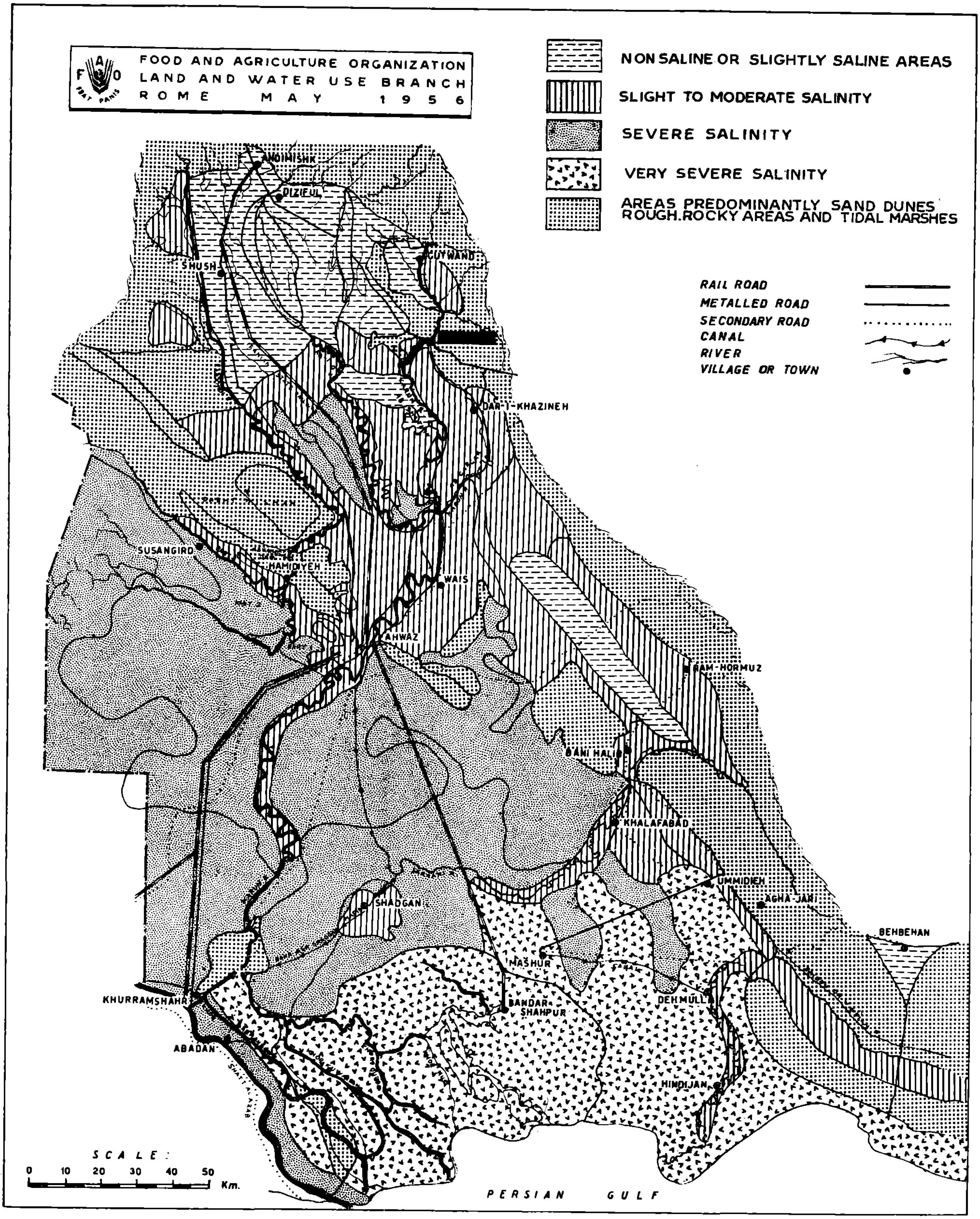

FIG. 1. Generalized soil salinity map of the Khuzistan Plains. (Prepared by Dr. M. L. Dewan.)

during and after the experiment by subjecting the ground-water samples taken to chemical analysis.

The irrigation water applied was gauged by a mobile Parshall flume, and its quality determined by analysing the water samples taken at the time of irrigation.

A detailed chemical analysis of water samples has been carried out in the Central Soils Laboratory. The detailed chemical analysis of soil samples has been completed to help in the evaluation of these leaching experiments, the results of which are summarized below.

SUMMARY OF RESULTS: EFFECTIVENESS OF LEACHING

1. In the check plots in which no irrigation water was applied there was no significant difference in the salt content of the various layers. If anything, there was a downward movement of salts, probably resulting from rain-water.
2. The leaching by 50–60 cm. of water in one of the plots reduced the salts considerably in the first 70 cm. to S0 or S1 level (less than 0.15 per cent and less than 0.35 per cent respectively) and probably averagely up to 1.5 m. on S2 level (less than 0.65 per cent).
3. Figs. 2 and 5 indicate the effectiveness of leaching for KL1, KL2 and KL3. Leaching by increasing amounts of water decreased the salt content in the layers, the depths of which increased roughly in proportion to the quantity of water applied. For example, as an average of four replicates, 50–60 cm. water (four irrigations) were able to leach the salt from the first 70 cm.; 100–120 cm. water from the first 100–130 cm.; 150 cm. from the first 150 cm. or so; and 200 cm. water from over 2 m. depth of soil.

TABLE 1. Experiments KL2 and KL3. Analyses of soil samples from 200 cm. leaching plots before and after leaching

Profile no.	Depth	Saturation	Total soluble salts		*p*H value			
					Paste		1 : 5	
			before	after	before	after	before	after
	cm.	%	%	%				
Exp. KL2	0–10	36.4	1.45	0.20	7.7	7.6	8.4	8.3
(Plot 2E)	10–40	46.0	1.80	0.18	7.9	7.9	8.4	8.2
	40–70	43.3	1.30	0.17	8.3	7.8	8.8	8.2
	70–100	53.5	1.70	0.20	8.0	7.7	8.7	8.2
	100–130	63.8	1.40	0.26	8.0	7.7	8.7	8.4
	130–160	65.0	1.30	0.38	8.1	7.7	8.7	8.4
	160–190	52.1	1.05	0.47	8.1	7.8	8.8	8.5
	190–220	32.2	0.60	0.21	8.0	7.7	9.2	9.1
	220–250	56.1	1.30	0.35	8.0	7.7	8.9	8.7
Exp. KL3	0–10	37.6	0.39	0.09	7.8	8.1	8.9	9.0
(Plot 14E)	10–40	42.6	1.55	0.16	7.5	7.9	8.1	8.5
	40–70	41.1	1.10	0.15	7.8	7.7	8.2	8.6
	70–100	39.8	1.15	0.15	7.6	7.7	8.2	8.4
	100–130	38.6	1.20	0.19	7.7	7.7	8.4	8.1
	130–160	32.5	0.70	0.19	8.0	7.8	8.9	8.3
	160–190	33.4	0.80	0.14	8.1	7.6	8.5	8.7
	190–220	44.7	0.90	0.35	8.1	8.0	8.5	9.2
	220–250	42.5	1.05	1.05	8.1	8.0	8.5	8.5
	250–300	34.9	0.93	1.35	8.2	7.6	8.6	8.5
	300–350	52.1	1.00	2.10	8.3	8.0	8.6	8.6
	350–375	62.5	1.05	1.10	8.3	8.2	8.6	8.7

TABLE 2. Experiments KL2 and KL3. Average saturation percentage and average total soluble salts for the plots with various leaching treatments

Plot no.	Sample no.	Average saturation		Average total soluble salts to 250 cm. depth	
		%		%	
Exp. KL2					
14A	14	47.6		1.71	
14A	63	49.0		1.55	
15B	15	45.9		1.30	
15B	36	50.8		0.82	
3C	3	50.2		1.30	
3C	48	53.3		0.70	
13D	13	49.8		1.53	
13D	53	54.1		0.32	
2E	2	49.8		1.32	
2E	60	53.6		0.27	
Averages		50.4	before leaching	1.45	
			after B	0.82	
			after C	0.70	
			after D[1]	0.32	
			after E[1]	0.27	
Exp. KL3					
8A	8	35.9		0.98	
8A	58	34.9		0.99	
17A	17	39.1		1.06	
17A	60	38.4		1.07	
3B	3	38.9		0.87	
3B	33	40.1		0.86	
20B	20	42.9		1.12	
20B	35	43.0		0.62	
6C	6	37.1		1.21	
6C	46	35.7		0.21	
12C	12	39.8		1.18	
12C	47	39.9		0.11	
2D	2	44.0		1.31	
2D	53	41.4		0.19	
15D	15	35.2		0.50	
15D	55	36.3		0.08	
5E	5	36.9		1.16	
5E	61	39.4		0.17	
14E	14	39.2		0.98	
14E	63	38.5		0.27	
Averages		38.8	before leaching	1.04	
			after B	0.74	
			after C[2]	0.17	0.18
			after D[2]	0.14	
			after E[2]	0.22	

[1] No significant difference between D and E, so leaching requirement is 150 cm.

[2] No significant difference between C, D and E, so leaching requirement is about 100 cm.

Table 3. Experiments KL1, KL2 and KL3. Analyses of irrigation and subsoil waters

Sample no.	Exp. no.	Source	Total soluble salts	pH	HCO_3	Cl	SO_4	Ca	Mg	Na	Sum anions	Sum cations	% Na	S.A.R.
			ppm.											
116	KL1	Irrigation water (barley test crop 1956)	496	7.9	1.75	2.60	2.82	2.60	1.80	2.83	7.17	7.23	39.1	1.9
87		Karkheh river water	1 040	7.4	3.30	5.85	4.64	4.85	3.15	6.15	13.79	14.14	43.4	3.1
88		Karkheh river water	932	7.7	2.45	6.20	4.70	4.00	2.80	6.71	13.35	13.51	49.6	3.6
103	KL3	Irrigation water	354	7.8	2.60	1.20	1.78	2.85	1.35	1.55	5.58	5.75	27.0	1.1
105	KL3	Irrigation water	594	8.1	2.70	3.15	2.55	3.55	1.80	3.38	8.40	8.73	38.7	2.1
94	KL2	Subsoil water	48 224	7.6	1.75	636.00	130.50	53.20	194.30	544.00	768.25	791.50	68.7	49.0
96	KL2	Subsoil water	55 700	7.1	3.45	780.00	76.26	117.60	241.90	539.00	859.71	898.50	60.0	40.0
97	KL2	Subsoil water	51 700	7.2	3.05	733.00	90.14	87.00	217.50	543.20	826.19	847.70	64.1	44.0
99	KL2	Subsoil water	58 800	7.0	4.30	872.00	59.89	164.50	240.00	545.60	936.19	950.10	57.4	38.0
100	KL2	Subsoil water	21 200	7.4	1.15	271.00	58.61	23.60	83.20	227.40	330.76	334.20	68.0	31.0
102	KL2	Subsoil water	51 300	7.2	4.90	712.00	102.40	88.00	214.00	536.20	819.30	838.20	64.0	44.0
110	KL3	Subsoil water	31 500	7.6	3.85	245.50	230.50	26.20	85.40	369.21	479.85	480.81	76.8	49.0
111	KL3	Subsoil water	35 500	7.7	3.60	256.00	269.90	25.80	92.80	429.48	529.50	548.08	78.4	56.0
113	KL3	Subsoil water	42 500	7.6	3.95	361.00	278.60	28.00	111.20	516.63	643.55	655.83	78.8	62.0
114	KL3	Subsoil water	23 600	7.6	1.75	230.50	132.80	20.80	65.40	283.75	365.05	369.95	76.7	43.0
115	KL3	Subsoil water	36 500	7.6	2.90	356.00	198.50	33.60	100.40	441.74	557.40	575.70	76.7	54.0
117	KL1	Subsoil water	51 700	7.4	3.05	568.00	228.90	37.00	211.00	563.33	799.95	811.33	69.4	51.0

Table 4. Experiment KL1. Summary of barley yields in plots with different degrees of leaching

Treatment	Centimetres of water for leaching	Average yield per plot of 150 m.^{2}		Yield per hectare	
		Grain	Straw	Grain	Straw
		kg.	kg.	kg.	kg.
A	Check	0.81	1.27	54	86
B	30	5.80	6.20	387	670
C	60	8.65	10.00	577	670
D	120	14.00	14.80	933	980

4. Fig. 6 shows the effectiveness of leaching as measured by growing a crop of barley on KL1. A test crop (barley) grown on plots of the Karkheh leaching experiment no. 1 (KL1–1955) showed a significant correlation between the growth and yield and the amount of water applied for leaching. Table 4 gives a summary of barley yields from plots with different degrees of leaching. Fig. 6 gives these results in graphic form. (See also Plates II–IV.)
5. Table 2 indicates that the two experiments KL2 and KL3 showed a significant difference in the texture of the layers. The average saturation percentage in up to 250 cm. depth was 50.4 in KL2 as against 38.8 in KL3. In KL3 the minimum of salt (from 1.04 to about 0.17 per cent) in 250-cm. depth of soil profile was reached with about 100-cm. leaching, whereas it took 150 cm. of water to leach the soil to the minimum salt content in KL2 (from 1.43 to 0.32 per cent T.S.S.). Not only did it need a greater amount of water to leach the KL2 type of soil, but the minimum salt reached (0.32 per cent), even with this water, was in KL2 much higher than in KL3 (0.17 per cent). The differences between these experimental sites indicate the great utility of the experiments conducted, and suggest that in certain broad areas leaching may not only be possible, but feasible and even practicable. The detailed soil surveys, coupled with the detailed chemical analyses and physical studies on permeability and infiltration rates, should lead the way to distinguishing areas which can be economically reclaimed from those which cannot.
6. Fig. 3 indicates that there was a slight rise in ground-water in all the three experiments. In KL1 the average rate of rise of ground-water was from 420 cm. to 410 cm. after 8 leachings of 15 cm. each, whereas a check well showed a fall from 450 cm. to 478 cm. In KL2 the water table, which was at 696 cm., 683 cm. and 696 cm. in W21, W22 and W23 respectively, came up to 640–650 cm. in the two holes W21 and W22 close to the plots being leached, and to 680 cm. in the W23, the check well being about 100 m. away from the plots. In KL3, W1 and W2, being at 515 and 520 cm. depth, came up to 494 cm. and 480 cm., and W3 from 530 cm. to 509 cm.
7. Fig. 4 indicates that there were significant differences in the infiltration rates recorded in the three experiments, and also in the progress of irrigation. In KL1 the rate after the two irrigations was about 2.5 cm. per hour, which decreased to about 1 cm. per hour at the last two leachings. In KL2, the average infiltration rate at the first three leachings was about 1 cm. per hour, which decreased to about 0.6 cm. per hour in the last two irrigations. For KL3, it decreased in four replicates from 0.6–0.7 to about 0.4–0.6 cm. per hour. To what extent the infiltration rates recorded in these experiments were related to relative alkalinity

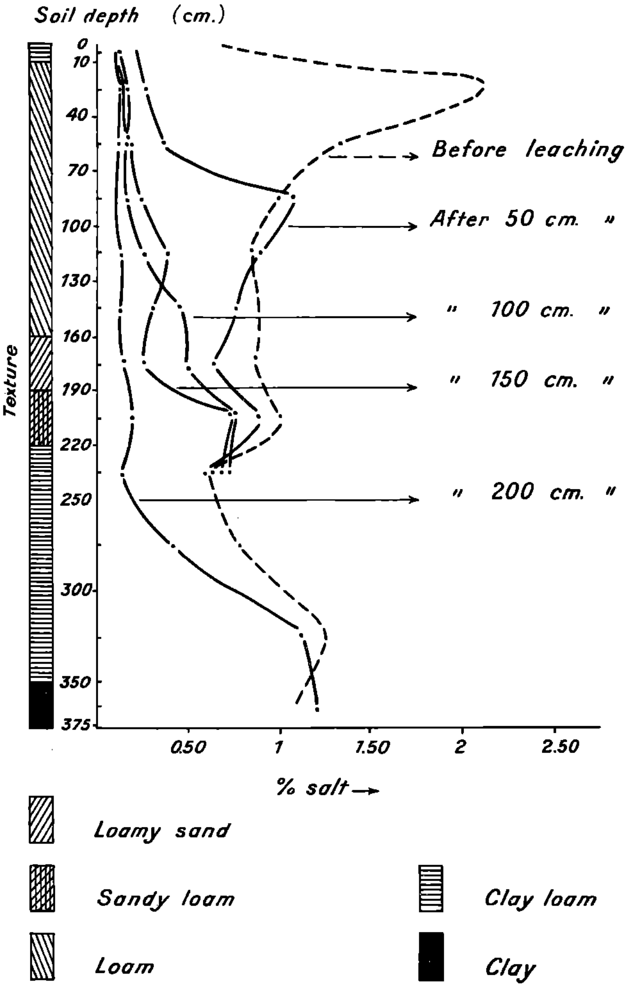

FIG. 2. Karkheh leaching experiment No. 3 (1956). Salt content of profile; average of 4 plots.

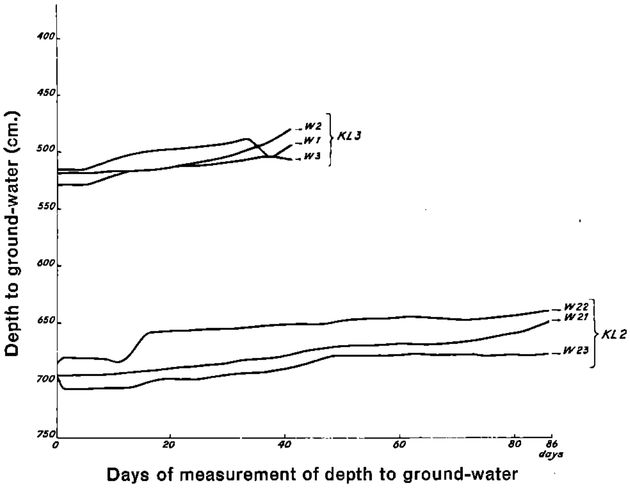

FIG. 3. Karkheh leaching experiment No. 3 (1956), KL2 and KL3. Variation in depth to the water table during the experiments.

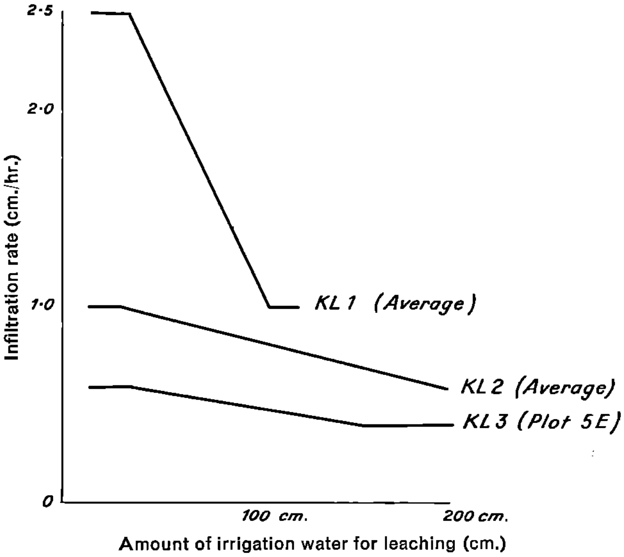

FIG. 4. Karkheh leaching experiments KL1, KL2 and KL3 (1955–56). Approximate relative infiltration rate.

is not fully known. However, the *p*H data suggest that in KL3 greater alkalinity is developed, especially in the subsoil, than in KL2 and KL1 (Table 1).

8. The quality of the irrigation water (Karkheh), as shown in Table 3, is moderate-to-poor for irrigation, depending on the season. Flood waters should be utilized for leaching; because of their better quality and increased quantity they are a favourable factor for leaching.

   The results obtained in all three experiments are fairly similar. The high salinity and high sodium absorption ratios of ground-waters (Table 3) reveal a great danger in their rise. It is obvious that other, similar, experiments should be conducted in large plots and fields, and then followed up by some suitable crops which would also help to determine the efficiency of leaching.
9. The ground-water tables are at a very low level and thus artificial drainage might seem unnecessary at this stage. However, the great danger involved in the rise of such ground-waters suggests that the studies should be conducted as soon as possible to determine whether these soils can be drained; if so, investigations and planning should be carried out with a view to the layout of such drainage systems. In addition, due allowance should be made, during the planning and layout of an irrigation distribution system, for the distribution of an additional amount of water for leaching the slightly too saline soils which form the bulk of the soils of the Karkheh irrigation project area.

ACKNOWLEDGEMENTS

These leaching experiments have been possible mainly as a result of the hard and persevering work of Mr. Bordbar,

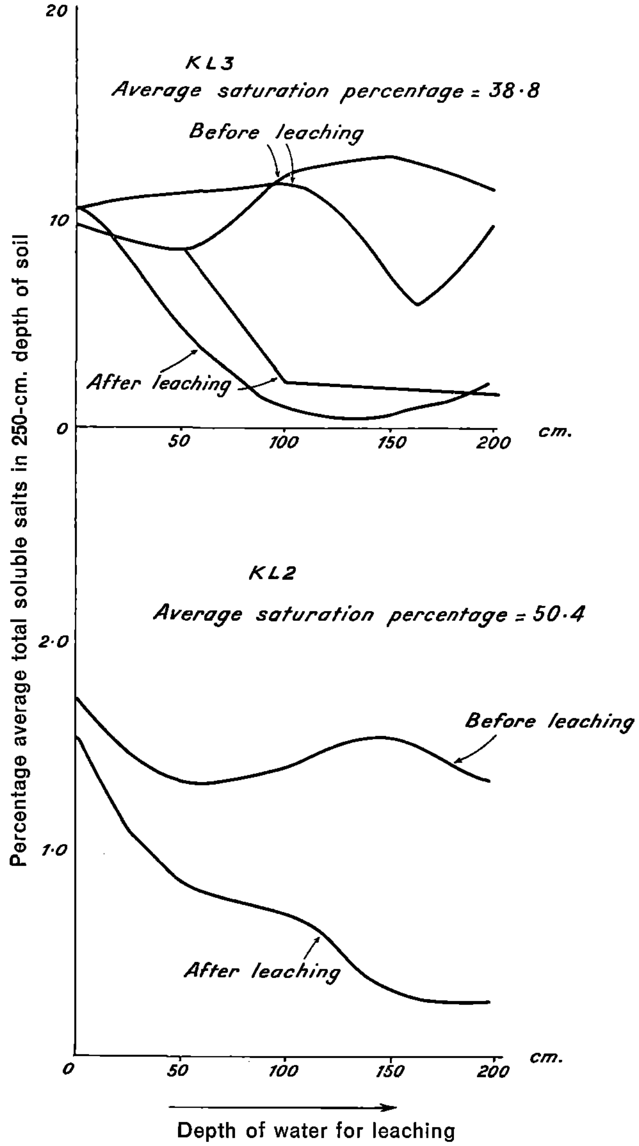

FIG. 5. Karkheh leaching experiments. Average total soluble salts in profile with varying depths of water for leaching.

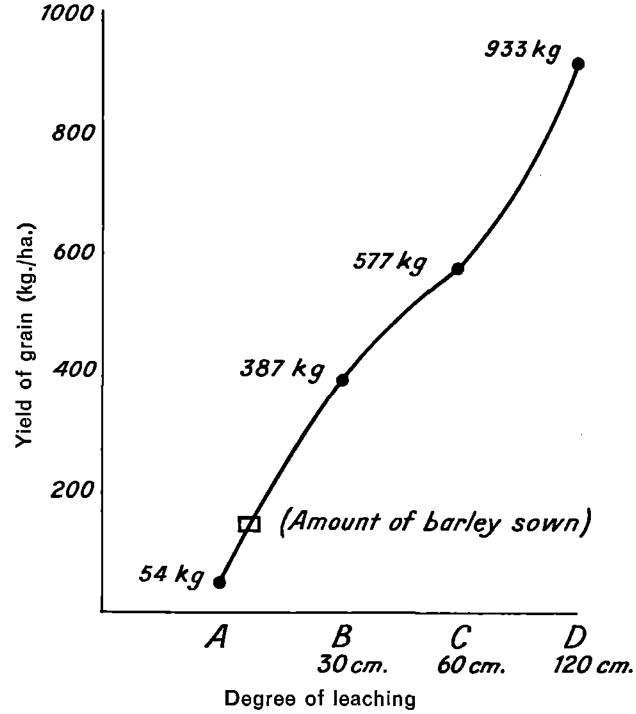

FIG. 6. Yield of barley grains in plots with different degrees of leaching.

civil engineer. In planning the experiments and selecting the sites assistance was given by Mr. B. N. Bulatkin, head of the Soils and Reclamation Section of ICA (Point IV) in Iran, whose initiative and interest have been very significant.

Acknowledgement is also due to the Independent Irrigation Corporation, which sponsored these experiments, and to the staff of Hamidieh farm who helped in many ways; to Dr. Gracie who also assisted in the selection of sites; finally, to the Soils Laboratory staff who analysed an extensive number of soil and water samples in connexion with these experiments.

RÉSUMÉ

Rapport abrégé sur les expériences de lessivage pratiquées dans la région de Karkheh, dans le Khouzistan (Iran) (M. L. Dewan et M. Bordbar)

Une expérience préliminaire pratiquée sur une parcelle a montré que le lessivage par des quantités croissantes d'eau diminue la teneur en sel dans des horizons du sol dont la profondeur est proportionnelle à la quantité d'eau fournie. Deux autres expériences de ce genre ont été faites en vue de déterminer les quantités d'eau nécessaires pour lessiver des sols à des taux de salinité différents, lorsque le lessivage doit s'effectuer à diverses profondeurs; d'évaluer la perméabilité du profil et ses modifications éventuelles pendant et après l'expérience; et enfin d'étudier le drainage naturel de la région et le rythme de relèvement du plan d'eau. Ces expériences ont montré que des études pédologiques précises, complétées par des analyses chimiques et des études physiques détaillées des taux de perméabilité et d'infiltration, permettraient de distinguer les zones économiquement récupérables de celles qui ne le sont pas. Une culture témoin d'orge a fait apparaître une corrélation significative entre la croissance de l'orge et son rendement, d'une part, et la quantité d'eau employée pour le lessivage du sol, de l'autre. Au cours des trois expériences, l'élévation du plan d'eau a toujours été faible, ce qui semble prouver l'inutilité d'un drainage artificiel.

DISCUSSION

I. **Zafar**. (1) What was the reason for the fall of the level of the ground-water table in the case of one of the experimental plots?

(2) What was the cost/land unit for the leaching that has been carried out so far to achieve proper reclamation of the soil?

M. L. **Dewan**. (1) The fall was in the check well, which was absorbed owing to a general lowering of the water table in the area (seasonal effect).

(2) As these experiments were conducted on small plots, 10 × 15 m., the cost of these leachings will be different from that of leachings on a large scale. These large scale leachings are planned and when conducted will give some idea of the cost of leaching per hectare.

M. M. **El-Gabaly**. (1) What was the duration of the leaching experiment?

(2) Was leaching continuous or intermittent?

(3) How could you explain the lowering in *p*H in the surface soil after leaching?

M. L. **Dewan**. (1) The duration of the leaching experiments varied. For two experiments (KL1 and KL3) it was about 40 days, and for one experiment, it was over 2 months.

(2) Leaching was intermittent. This method was adopted so as to take soil samples and follow the movement of salts in the soil.

(3) The *p*H data given do not show any statistically significant change in *p*H with the progress of the experiment, though in some cases it appears to be lower and in other cases it is slightly higher, or unchanged.

G. **Drouhin**. Quelle est la texture des sols soumis à l'expérience de lessivage?

M. L. **Dewan**. The texture of the soil varied to some extent in each of the experiments. But, as shown in fig. 5, the surface texture was clay loam, with varying layers of loam, loamy sand and even clay in addition to clay loam down to about a depth of 375 cm.

T. **Jewitt**. (1) What was the calcium carbonate content of the soil?

(2) Does Dr. Dewan think that this played a part in the apparently rapid and successful leaching process?

M. L. **Dewan**. (1) The Karkheh soils on which the experiments were carried out have usually between 30 and 50 per cent $CaCO_3$.

(2) I think that this $CaCO_3$ does play a part in the moderately rapid leaching, and in addition the gypsum present in the soil also helped in this leaching.

THE SYSTEM OF RECLAMATION METHODS FOR EXPLOITING SALINE AND SWAMPED SOILS AND AGAINST SECONDARY SALINIZATION OF IRRIGATED SOILS IN TADZHIKISTAN

by

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Beginning in 1936, under the guidance of the present authors, reclamation methods were developed in Tadzhikistan in order to exploit saline and swamped lands. One of the main projects of irrigated territories is represented by the Vakhsh Valley. Taking this project as an example, a system of reclamation methods will be examined in this report.

The elements of this system of reclamation methods on irrigated soils may be divided into two groups: (a) Hydrotechnical methods, aimed at regulating the water and salt balance within the limits of the irrigation system; (b) agrotechnical methods.

The first group includes methods aiming at: (a) increasing the efficiency of the irrigation system and the utilization of irrigation water; (b) lowering the ground-water level and increasing the carrying away of salts beyond the limits of the irrigated territory.

The second group includes measures for increasing the fertility of soils and for reducing their reserves of water soluble salts. Such methods may be applied one at a time; for instance, leaching of saline soils, deep ploughing of solonetz-saline soils, etc.

The efficiency of the irrigation system may be raised: (a) by straightening and reducing the length of the irrigation network, and by lowering the relative level of the fields in the ancient irrigation systems; (b) by increasing the size of watered plots; (c) by reducing the number of water discharges; (d) by reducing the water debit in winter time; (e) by placing antifiltration coatings on canals, etc.

The lowering of the water table and the raising of the quantity of salts transported beyond the limits of the irrigated territory are carried out with the help of the drainage network which, in the past, has been of the horizontal closed type. Research is now being carried out on the possibilities of changing from the horizontal closed drainage system to a vertical one, with mechanical pumping of ground-waters to be used for leaching of saline soils and for irrigation.

The parameters of the drainage network were determined according to data on the so-called critical occurrence depth of the ground-water, this being related to its degree of mineralization.

In order to ensure that the salinization of soils does not exceed acceptable values where the mineralization of the ground-waters is high, the water table must be lower than is the case with weak mineralization. Under conditions existing in southern Tadzhikistan the critical depths and mineralizations of ground-waters were found to be as shown in Table 1.

TABLE 1

Critical depth of ground-water level in m.	*Acceptable mineralization of ground-waters* in gm./l.	
	Total	Chlorine
0.8–1.0	near 1	0.17
1.0–1.5	1–2	0.17–0.27
1.5–2.5	2–3	0.27–0.37
2.5–3.0	3–5	0.37–0.60
more than 3.0	more than 5	more than 0.6

Depression curves of the water table were determined in the field; they depended on the depth of the drains and the structural characteristics of the drained subsoil. On the basis of the results obtained by various investigations, and of data concerning critical depth and ground-water mineralization, it is suggested that the drains be laid on plots with high water tables. The drainage collectors are marked out along the maximum slope of the territory—on the low land between irrigation canals; this stimulates their bilateral action. The depth of the drainage collectors is 3.0–3.5 m., on the lowest part of the territory. The water level in the collector does not exceed 0.4–0.5 m. Where broad plots exist on plains, additional drains with depths of 1.5–2.5 m. are being laid, some of these drains are temporary, being used only in the initial period. This was found possible because in the course of this period of soil reclamation the mineralization of ground-waters decreases and their critical level falls. Consequently the danger of the salinization of soils, when the ground-water level is higher than at the beginning of the reclamation period, also decreases. It was found that the density of the collector drainage network must be, on the average, 13–15 running m./ha. A drainage modulus of the order of 0.25–0.35 is sufficient.

The leaching of saline (alkaline) soils on a drainage basis has as its purpose a reduction in the salt quantity of the entire area—i.e. in soils, subsoils and ground-waters. Thus the possibility of recurring salinization is obviated, if the drainage installations are maintained in action. Such measures are advisable in areas with pronounced soil salinization and with large reserves of easily dissolved salts.

In areas with comparatively weak salinization, with a small reserve in salts, salinization of soils may be remedied by appropriate agrotechnical methods. In the example given the concentration of easily soluble salts in the upper soil layers decreases mainly as a result of the redistribution of salts in vertical and horizontal directions within the soil mass, the subsoil and the ground-waters.

In the process of leaching the soils, one distinguishes the intensity and the rate of desalinization. The intensity of soil desalinization is determined by the quantity of easily soluble salts in relation to the initial salt reserve in the soil. This depends on the composition of the salts and the physical properties of the soil. As a volumetric unit of water, one takes (according to the proposition of Professor L. P. Rozov) a volume equivalent to the field moisture capacity of the soil mass to be desalinized. We define the percolation of water through the soil mass, in the volume of field moisture capacity, as a complete replacement of the soil solution.

The rate of desalinization is determined by the time in which the indicated volumetric unit of water filters through the soil.

Observations concerning the leaching of alkaline soils have shown the great extent to which chlorides are washed out. (See Table 2.)

TABLE 2. The quantity of chlorides washed out of the soil (in per cent of the initial content) in the course of leaching of chloride-saline soils with various quantities of water[1]

Depth of soil from surface in cm.	Water added to field moisture capacity (4,000 m.^{3}/ha.)	1 replacement of solution in 0–100-cm. soil layer (7,000 m.^{3}/ha.)	2 replacements of solution in 0–100-cm. soil layer; 1 replacement in 0–200-cm. layer (10,000 m.^{3}/ha.)	3 replacements of solution in 0–100-cm. layer 2 replacements in 0–200-cm. layer; or 1 replacement in 0–300-cm. layer (18,000 m.^{3}/ha.)
50	39	97	98	99.5
100	13	86	97	99.3
200	0	58	95	98.0
300	0	50	69	80.0

1. Data obtained by O. A. Grabovskaya.

The structure of soils up to average aggregate dimensions (less than 5 mm.) does not in practice affect the extent to which salts are carried out, but quickens the process considerably. A coarse structure (lumpiness, or a fissured state) strongly decreases the extent of desalinization. A heavy mechanical composition of the soil and a high water table also decrease the extent of desalinization, and strongly delays it. (See Table 3.)

TABLE 3. Extent to which Cl' and SO_4'' are carried out of 1-m. thick layers of saline soil, with varying mechanical compositions, in the presence of one and two replacements of solution[1]

Depth of ground-waters	Physical composition	Flush norm in thousand m.^{3}/ha.	Extent of washing out of salts (% of initial reserve)		
			Cl'	SO_4''	Number of replacements of solution
2.0–2.5	Light sandy loam	4–5	81–86	68	1
		6–7	96–98	71	2
1.5–2.0	Medium sandy loam	4–5	67–68	—	1
		6–7	86–87	78	2
1.0–1.5	Heavy sandy loam	4–5	32–83	—	1
		6–7	69–87	56	2

1. Data obtained by O. A. Grabovskaya.

If a twofold replacement of solution takes place, up to 95–97 per cent of chlorides are carried out of soils of uniform composition, and from 50–55 per cent out of soils of non-uniform composition. Leaching with small quantities of water has a marked desalinization action only under the most favourable desalinization conditions.

Temperature conditions obtained during leaching with large quantities of water do not play an important role, because the quantity of water supplied markedly exceeds the quantity needed to dissolve the easily soluble solid sulphates. No less than a twofold replacement of solutions is needed for the complete desalinization of alkaline soils.

For the normal development of the cotton plant under conditions such as those obtained on the Vakhsh Valley, the admissible Cl' content in the soil is about 3 t./ha. within the first metre. Therefore, the leaching of alkaline soils aims at lowering their Cl' content to this value. The quantity of water needed to achieve this is determined by taking into account the salt reserve in the soil, the intensity of leaching and the residual quantity of chlorides that is acceptable.

In practice, according to the salt reserves observed in the Vakhsh Valley, the leaching quantity for alkaline soils is 10,000–12,000 m.^{3}/ha. In the case of heavy mechanical composition, when water filtration into the soil is slow, leaching of alkaline soils is carried out at the same time as the cultivation of irrigated rice; this is done during one year, and sometimes two.

The leaching of saline soils is carried out at any time of the year, the optimum time for it being the end of summer and the autumn, before the winter rains.

In the past years, leaching of saline soils was carried out in the furrows and followed by sowing of grass—*chabdar* (Persian clover) and ryegrass (Italian clover)—which are tilled in the spring. This method is applicable on saline soils of light mechanical composition.

Stretches of highly saline soil in cotton fields are leached during the summer-autumn period. During vegetation watering, an additional quantity of water (6,000 to 8,000 m.^{3}/ha.) is given to the saline stretches.

In order to desalinize slightly and moderately saline soils only 3,000–4,000 m.^{3} of water per hectare are necessary. Therefore their reclamation is limited to the application of certain additional agrotechnical methods, such as moisture retention waterings in the autumn, and in the winter, provision of increased quantities of water in comparison with non-saline soils.

The solonetz-saline dense soils are submitted before leaching to a deep (down to 30–40 cm.) tilling, in order to destroy the dense layer.

Continued desalinization of saline soils after their leaching is secured by a complex of agronomical methods:

1. Additional waterings in late autumn to complete the desalinization.
2. Autumn ploughing before the rain period.
3. Levelling of the micro-relief.
4. Early spring waterings for the desalinization of the soil profile.
5. Vegetative waterings. It is recommended that these be carried out according to the moisture deficit in the soil, assuming that soils drying before the next watering would have less than 65 per cent of the field moisture capacity in the first 1–5 m. of soil. The quantity of water required is determined here as 35–40 per cent of the field moisture capacity. It is also recommended that the waterings be carried out at night; in the spring it is expedient to carry them out during rain.
6. Scarifying after watering. It is necessary to scarify the soil surface when crops are observed to be ripe.

As is known water applied for leaching saline soils, and irrigation water in general, must not bring about solonetz-like processes in the soil. In this respect a special isotope method, based upon the principle of adsorption-desorption processes (I. N. Antipov-Karataev and G. I. Kader), has been elaborated for determining the water quality. With this method it is possible to determine the "critical" equivalent relation of alkali earth cations to alkaline cations in irrigation water.

By the critical relation—Ca : Na or (Ca + Mg) : Na—the authors mean an equivalent relation of these ions in the solution (of irrigation or leaching water) such that, if the soil is washed by a solution of this kind up to an ion-exchange equilibrium, it causes an adsorption of sodium to the extent of 10 per cent of the exchange capacity of the given soil. It is known that with such an exchangeable sodium content soil alkalinization begins (Mamaeva [4][1]). As may be observed from data obtained in special investigations by Antipov-Karataev and Kader [3] and given in Table 4, the value of the critical relations Ca : Na and Ca + Mg : Na depends upon the degree of the total mineralization in the irrigation or leaching water. The same investigations show the absence of a dependence of this value on the cation-exchange capacity of the soil.

TABLE 4. Absorbed quantity of Na as percentage of the soil exchange capacity in the various relations Ca : Na, Mg : Na and Ca + Mg : Na, in solutions of different concentration

Salt concentration in gm./l.	Relation of bivalent cations to monovalent cations in solutions					
	4:1	3:2	1:1	2:3	3:7	1:4
In competition of Ca with Na						
0.5	2.5	2.9	3.2	3.9	5.5	7.3
1.0	weak	3.6	4.5	5.5	7.9	*9.6*
3.0	weak	3.6	9.0	*10.0*	11.1	19.3
5	weak	3.6	*13.3*	14.3	15.1	—
In competition of Mg with Na						
1	2.4	3.6	4.4	6.4	8.4	*10.6*
3	3.6	4.8	7.6	*11.9*	13.9	20.3
5	4.8	6.8	*9.9*	15.5	17.5	23.9
In competition of Ca + Mg with Na						
3	—	—	—	8.7	*10.3*	14.3

N.B. The critical values of the exchangeable Na are in italics.

Table 4 shows that the critical value of exchangeable sodium in the soil (about 10 per cent of the exchange capacity) depends, firstly, on the degree of mineralization of the water and, secondly, on the value of the equivalent relation in the solution of divalent to monovalent cations Na. If the mineralization is 0.5–1 gm./l. of salts, the critical relation moves towards large specific quantities of sodium in the solution (up to 80 per cent and more of the cation total); if the mineralization is, however, 3 gm./l., the critical value of exchangeable sodium is established when the specific participation of sodium ions in the solution is about 60 per cent; in the presence of 5 gm./l. of salts in irrigation water, and of 50 per cent sodium ions in the solution, the alkalinity of the soil is even higher. Concerning the competitive relation of Mg and Na, and of Ca + Mg and Na, the critical relations are only slightly different from those in the competition of Ca and Na. In this manner, on the basis of these investigations, essential modifications are made to the qualitative and quantitative standards of evaluation of irrigation (and leaching) water, as presented in the specialized literature.

The system of reclamation methods described above

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[1] The figures in brackets refer to the bibliography on page 284.

was tested with success on three experimental production plots (2,000 ha. each), and is largely developed in practice. As a result of this and other methods, the crops of the Soviet fine fibre cotton plant grown in the Vakhsh Valley have been increased by 1.7 times since 1940 (average crops in the valley equalled 22 centner per hectare in 1956); the total crop of raw cotton increased by 2.1 times.

RÉSUMÉ

Mesures systématiques de recupération appliquées dans le Tadjikistan en vue de mettre en exploitation des terrains salins et marécageux et de prévenir la salinisation secondaire des sols irrigués (I. A. Antipov-Karataev et P. A. Kerzum)

C'est en 1936 qu'ont été entrepris dans la RSS du Tadjikistan, sous la direction des auteurs, des travaux visant à la mise en exploitation de terrains salins et marécageux. Les travaux d'irrigation ont eu essentiellement pour objet l'aménagement de la vallée de Vakhsh. Ils s'inscrivent dans un plan plus général de mesures de récupération comprenant les activités suivantes: drainage par un réseau de collecteurs, labourage profond des sols salins, élimination des sels par lixiviation, mise en œuvre d'une série de procédés agronomiques d'amendement (action sur la nature des sols, emploi d'un choix d'engrais; application d'un régime rationnel d'arrosage, etc.)

Grâce à ces mesures, et à d'autres qui les complètent, on est parvenu dans la vallée de Vakhsh à multiplier par 1,7, depuis 1940, le rendement de coton soviétique à fibres fines. Le rendement moyen y était de 22 quintaux à l'hectare en 1956; la récolte de coton brut a été multipliée par 2,1.

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DRAINAGE AND RECLAMATION PROBLEMS IN THE GARMSAR AREA

by
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The Ministry of Agriculture decided to establish a research station to determine the practical and economical methods of reclaiming the unproductive saline and alkali soils of the Garmsar district.

The desert area selected for the research work is situated in the southern part of Nouredin village and an experimental station has been established for drainage and land reclamation purposes. Also, development work will start over an area of approximately 1,000 ha.

LOCATION AND AGRICULTURAL CONDITIONS

Nouredin village has an elevation of 810 m. above sea-level (fig. 1). The area of cultivated and undeveloped land of the village is about 90 ha. The areas used for cultivation are as follows: autumn and spring farming, 25 ha.; orchards, 7 ha.; gardens, 20 ha.; fallow fields, 30 ha. The yield is rather low because the land was part of a desert that the local farmers have developed during the last seven years, without using adequate methods. The fields are semi-cultivated or uncultivated, the water table is high, and the soil is rather saline, hence crop growth is low. The wheat production of the area in 1957 was about 5 tons and in 1958 about 10 tons. The inhabitants of the village, which consists of 40 homes, have turned mostly to ranching.

Nouredin has six kanats. One, which was excavated about 27 years ago, was originally excavated to lower the underground water table in the upper areas; the water comes to the surface of the land in the Nouredin fields. In the years 1949–56 this kanat was extended and the flow is now 150 l./sec. (April 1958). The length of the kanat between the mother well and the place where the water flows onto the surface is about 1,100 m. The water is rather hard and its salt content is 2,240 ppm. (third class water). Another kanat was excavated in the years 1955–57. Its purpose was to drain the area through which it passed. The flow of this kanat is 60 l./sec.; the water is not utilized and flows into the desert. In the past correct and serious work has not been accomplished.

DRAINAGE INVESTIGATION IN THE SELECTED DESERT AREA

Investigations were carried out on drainage problems. The topographic map of 1,110 ha., which was drawn for the purpose, shows a steady and uniform slope from north to south of approximately 3–4 metres per kilometre.

On the desert under study there are no gullies, hills, breaks in slope, or eroded patches. The existing feature is a natural drain starting about 2 km. down from the upper edge of the land and ending in the lower edge. The depth of this drain is 40–80 cm. at different points and the width at the top is around 1 m. This drain takes the surplus water from a few springs in its path and also the drainage water of its surroundings to the end of the selected desert patch. In the summer season, as the water table is low, this natural drain is dry. The other features of the patch are four other shallow drains, along the northern edge of the patch, the lengths of which are around 400–500 m., and the depth 1 m. These drains were excavated in 1955–56. Since these drains do not have proper cross-sections and are not adequately maintained they are deteriorating. At present they are not efficient from the drainage point of view.

Four springs exist in the selected area. These springs are located in the low lands of the desert and are forming marshy fields where they penetrate the surface. The water springs out from a depth of about 6 m. The water is rather soft and is used by local ranchers.

The analysis of these spring waters indicates the characteristics shown in Table 1.

Table 1

Location of water sample	Date of the sampling	Total salts
		ppm.
Rashmeh Guy spring	May 1958	1 400
Shurguy spring	May 1958	490
Kurkulan spring	June 1958	1 856
Guyelar spring	June 1958	1 856

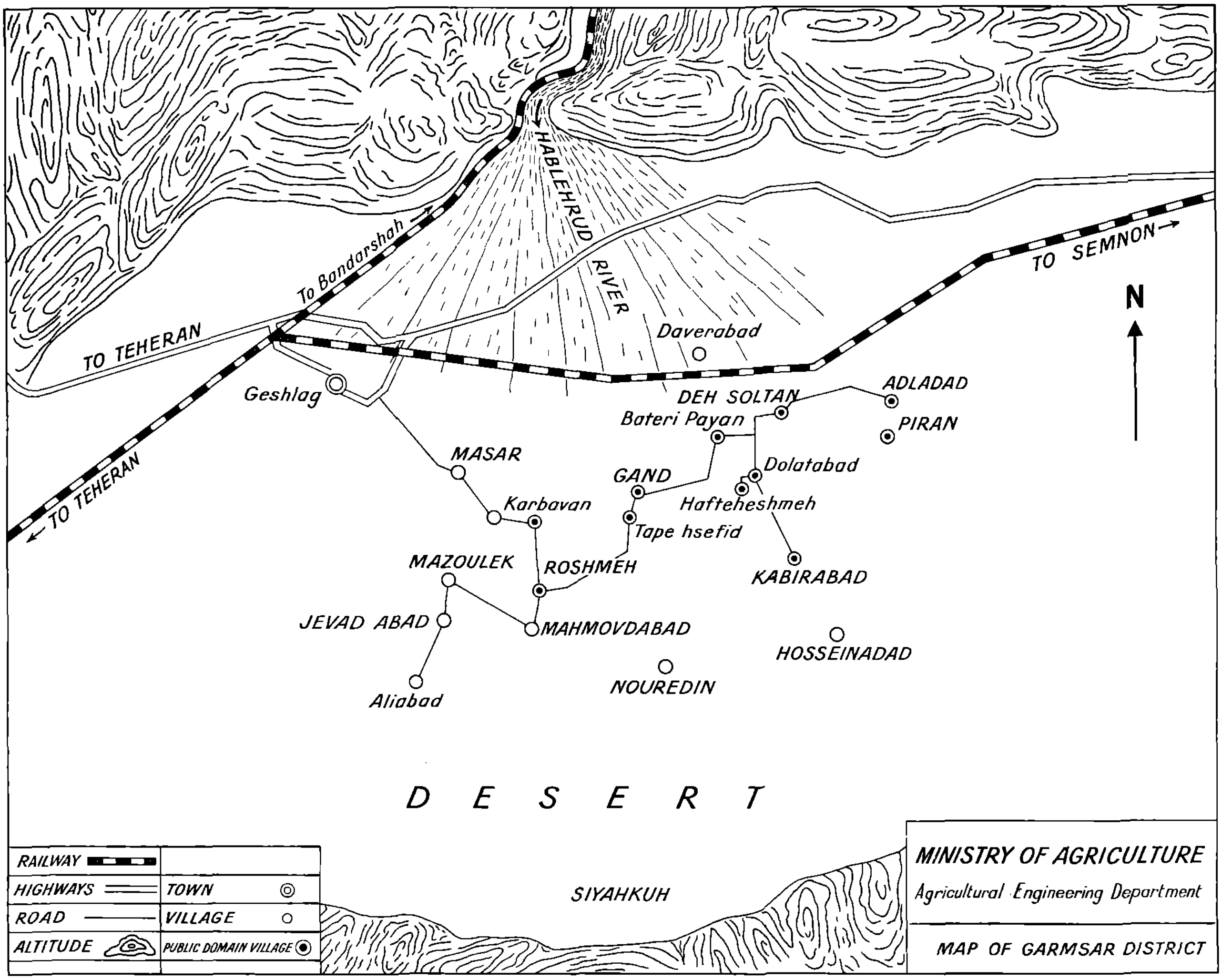

FIG. 1. Map of Garmsar district.

Soil investigation

Soil investigations have been carried out, especially on the texture and stratum survey and for total salt content within a depth of 3 m., in co-operation with technicians from various departments.

The figures of 200 samples of soil in the area of 1,100 ha. to a depth of 3 m. show that the salt content ranges from 0.45 to 3 per cent. Tests show that the soil has less and less salt as it gets deeper from the surface. It even reaches a percentage at which the soil is satisfactory for cultivation. Most of the tests show the salt content to be 1.5–3 per cent.

Probably the most important single technical phase of the drainage investigation is the soil-stratum survey which gives the location and physical characteristics of the various underlying soil layers.

Four investigation lines have been established and piezometers have been put on the lines at a depth of 2 m. and at intervals of 300 m. Auger holes have been dug beside each piezometer to a depth of 3 m., to assess the soil profiles.

As is obvious on the profiles of four axes the top soil changes between the ranges of 40–80 cm. In depth a permeable sandy loam layer is formed. The interesting thing is that we rate this soil, as it is permeable, in the SL category, but agricultural soils of the SL type really do not exist. Perhaps, in the years past, through evaporation and the accumulation of salt at the surface, gypsum crystals ($CaSO_4$, $2H_2O$) especially have formed a distinctive granulation. This layer of the soil, because of the great quantity of soluble salt it contains, has a brownish white colour. The chemical tests show that there is a great quantity of gypsum in this layer. Even during the testing procedure flocculation takes place. Exchangeable sodium is very noticeable and its presence is proved, but lime content is very low or does not exist.

A chemical indicator has shown the *p*H of this layer to be ranging between 8 and 10, and in the long run to be 9. After this layer, there is some silty clay. This layer is of a rather medium texture type. The layer that is lower than about 2 m. is silty clay and clay, which have a great influence on natural drainage. In some profiles, at depths ranging from 1 to 3 m., there are some light layers such as sand, sandy loam and gravel.

The existing layers, of olive and grey colour, are like the formation of the hills and cuts in the northern area of the Garmsar Plain, and show very clearly that they are of the same formation. Remnants of vegetation and the kind of roots found in the soil layers, also the appearance of vegetation features, prove that this desert was for some years in the past a marshy area.

Soil analyses

Dissolved salt. About 200 samples of the soil, from 0 to a depth of 3 m. down, were taken from different and suitable points. The salt content was measured by using a conductivity bridge. At a point A1, from a depth of 0 cm. down to 300 cm., five samples were taken. The salt content ranged from 0.45 to 3 per cent, and as a whole the salt content decreased as the samples were taken from lower sections. Considering the results of tests carried out at other points, A2 and A3, the salt content of samples taken in a section deeper than 1 m. was too high. In reality the salt content is much lower, but in the process of sampling the samples were mixed with some surface material, thus showing a high percentage of salt.

pH of the soil. The *p*H of soil is found approximately by means of a *p*H blue indicator, as follows: in the upper layers (from 0 cm. down to 100 cm.), as the salt has been accumulated in the past years, the *p*H of the soil is high, ranging from 8 to 10; as a whole it is about 9. Thus the quantity of exchangeable sodium is large in this sandy loam layer and naturally it is rated as a saline-alkali soil. Luckily this layer holds a large quantity of gypsum crystals providing a suitable condition for land reclamation.

As is shown below, the chemical reactions taking place in the process of reclamation facilitate the possibility of the work:

$$CaSO_4 + Na_2CO_3 \rightleftarrows CaCO_3 + Na_2SO_4 \text{ (leachable)}$$
$$CaSO_4 + Na \text{ (clay) } Na \rightleftarrows Ca \text{ (clay) } + Na_2SO_4 \text{ (leachable)}$$

As sodium sulphate (Na_2SO_4) is leachable the sodium will disappear by leaching.

The study of soils that have been reclaimed in recent years. Samples taken in the areas of Dehnagsh and Nouredin villages that have been reclaimed in recent years by non-technical procedures are very interesting. Samples were taken at two different places in the Dehnagsh area and tests carried out. The results are as shown in Table 2.

TABLE 2

No. of sample	Salt content	Depth of soil	Salt content	Depth of soil
	%	cm.	%	cm.
Lab. no.	0.34	0–60	0.25	0–20
213–222	0.31	60–100	0.31	20–40
	0.46	100–160	0.19	40–80
	0.49	160–240	0.18	80–160
	0.53	240–260	0.38	160–300

As will be noticed, these changes in the profile of the soil in the first year of reclamation are worth considering.

The samples of the soil of Nouredin taken in the orchard owned by Alimeded, the reclamation of which was started about 20 years ago by means of non-technical methods, have been analysed and the results are shown in Table 3.

TABLE 3

No. of sample	Salt content	Depth of soil	Salt content	Depth of soil
	%	cm.	%	cm.
Lab. no.	—	—	0.34	0–20
223–231	0.17	20–60	0.25	20–100
	0.22	60–120	0.23	100–160
	0.25	120–200	0.26	200–300

The results obtained from the soil of Nouredin where wheat and alfalfa are cultivated were as shown in Table 4.

TABLE 4

No. of sample	Wheat field		Alfalfa field	
	Salt content	Depth of soil	Salt content	Depth of soil
	%	cm.	%	cm.
Lab. no.	0.53	0–20	0.22	0–20
241–251	0.38	20–60	0.21	0–50
	0.18	60–140	0.20	50–160
	0.16	140–180	0.20	160–240
	0.19	180–240	0.18	240–300
	0.20	240–300		

Alimeded has been able to develop some 30 ha. of desert land in the Nouredin area over a period of several years. He has established an orchard in this area. The feature that was considered interesting at Alimeded's orchard was the lack of deep and adequate drains. He stated that in the last 20 years his trees had perished twice on account of the rise of the underground water table beyond the allowed limit. He replanted the trees. The reasons for this rise of the underground water table were assumed to be heavy precipitation over the Firouzkuh mountains, full flow of the Hablehrud, heavy floods and surplus water from irrigated up-lands which affect the rise of the underground water table in low lands. In normal years, this area being slightly higher than the neighbouring areas, the water table is rather low. In the month of May 1958, the underground water table was found to be 180 cm. below the surface. If a deep drain were excavated in the above-mentioned orchard good agricultural results could be obtained. The crops raised in this area are wheat, alfalfa, melons and cotton, but not much. The trees planted in the last few years are some fig, mulberry, pomegranate, apricot, apple and Hungarian olive trees. This orchard is located in the north-eastern part of the selected desert area and is therefore worth developing.

Water table investigation

To study the fluctuations of the underground water table a grid pattern is established over the entire selected area. Piezometers have been put across the grid at 154 points, and at intervals of 300 m. These piezometers are 2–5 m. long and their diameter is about 0.9 cm. The depth and fluctuation of the underground water table in different months, starting from March 1958, were measured, recorded and graphically plotted. The depth of water on 24 March 1958, at different points ranged between 20 cm. and 100 cm. Generally, in the northern sections of the area close to Nouredin, the underground water table was higher; it was generally lower in the southern sections which are close to the desert. During March 1958 the underground water table was at a depth of less than 100 cm. During the next months of the year the underground water level receded to a maximum depth of 1.80 m. The records show that during May and June 1958, in the northern section of the selected desert, the underground water level had fallen to a depth of 100 cm.

Water source survey

As the fluctuations of the underground water table were under observation the sources of drainage water were carefully considered. According to the studies carried out the sources of drainage water of the Garmsar Plain are influenced by the following factors:

1. As the soil of the district is saline, the farmers leach their land as much as possible during the Hablehrud flooding season. The surplus water penetrates to the lower areas, thus raising the underground water level.
2. In the distribution of the Hablehrud, the only river of the area, technical aspects are not considered at all. Water measurements are not taken, and the canals and ditches are not lined. As has been stated above, the northern area of the plain is very permeable and a great quantity of water in the canals and ditches is wasted through seepage losses, penetrating into lower areas of the plain and consequently raising the underground water table tremendously.
3. Since water measurements are not properly carried out and the farmers do not care for technical methods, irrigation water is used in excess, thereby raising the underground water table in the lower areas.
4. In order to check probable artesian pressure in the Garmsar district a piezometer cluster was set at a depth of 6 m. Results show that artesian pressure does not exist. But a definite statement cannot be made as yet and the investigation will continue in order to obtain final results.

Kanats

Among the implements for agriculture and irrigation in Iran, kanats are very important and in the very old days were popular with our ancestors. In the areas where proper grades of water exist these kanats are developed to take advantage of underground waters. In the Garmsar district several kanats have been developed in recent years. Generally speaking, there are kanats in the villages in the extreme south of the Garmsar district, their number depending on the grade and depth of the underground water. In these southern villages of the Garmsar Plain, as the underground water level is high, the length of kanats is short, but the salt solution is rather great and all kanat waters are hard. The kanat waters are used to compensate the deficiency of the Hablehrud river. These kanats are as a rule developed in order to drain the underground water in desert areas. In recent years, with the farming activity increasing, water has become insufficient and kanats have been developed.

The results of the analysis of some kanat water in the Garmsar region are shown in Table 5.

TABLE 5

Name of kanat	Sampling date	Salt content
		ppm.
Mohamedabad	May 1958	2 600
Adlabad	May 1958	2 100
Saidabad	May 1958	2 400
Nouredin	May 1958	2 240

Results and plans for the future

The studies made in this district and the results obtained are as follows:

1. This district is a centre for the following crops: wheat, cotton, melon, pomegranate and figs. As it is close to Teheran the fruit sell well.
2. In this district the cost of land which has long been reclaimed is about 5–8 times higher than that of land

reclaimed recently. As the cost of reclamation of this land is not high, owing to the availability of equipment, it is worth consideration for any aspect of economy.

3. Technical studies, including such factors as meteorology, soil, water, drainage possibilities and reclamation; the activities of the Public Domain and those of landowners as regards drainage and land reclamation (although these are not correct and adequate); all promise a good future.
4. Since the drainage and land reclamation of this area is of the utmost interest to both landowners and the Public Domain Bongah, and since the results obtained are satisfactory, drainage and reclamation projects will be carried out. It should be added that before extensive development takes place a small area will be under experiment to ensure that the methods and reclamation processes are adequate, bearing in mind the depth and distance between the drains.

RÉSUMÉ

Les problèmes de drainage et de mise en culture des terres dans la région de Garmsar (M. Ayazi)

L'auteur rend compte des travaux de la station de recherches que le Ministère de l'agriculture a établie dans la partie méridionale de la commune de Nouredin afin d'élaborer des méthodes simples et économiques de mise en culture de friches salines et alcalines de la circonscription de Garmsar.

Le terrain d'expérience choisi avait une superficie d'un millier d'hectares, une pente uniforme nord-sud de 3 à 4 mètres par kilomètre et un drainage naturel efficace; il s'y trouvait quatre sources. Le sol contenait entre 0,45 à 3 % de sel et l'on a procédé à des sondages méthodiques à quatre profondeurs différentes. Dans des échantillons de terres déjà en culture depuis quelques années, on a constaté une réduction considérable de la teneur en sel. La profondeur et les fluctuations de la nappe souterraine ont été mesurées et enregistrées en différents mois de l'année, et l'on a déterminé l'origine des eaux de drainage. Les habitants des régions désertiques ont souvent recours, pour drainer les eaux souterraines, à des kanats, lesquels tendent à se multiplier à mesure que l'agriculture se développe.

Les expériences ayant donné de bons résultats, des travaux de drainage et de mise en valeur des terres ont été décidés.

DISCUSSION

I. Zafar. Could you please say if tiled drains were tried in addition to the open drains at any point, and how do their costs compare?

M. Ayazi. (1) Till now we haven't a tile drainage system in Iran, but actually the kanats work as an underground tile drainage system.

(2) The cost of establishing a tile drainage system is about twice that of an open drain, but it is permanent.

R. Ambroggi. (1) Quelle est la longueur totale des 30 kanats dans la région de Garmsar?

(2) Quel est le débit total de ces 30 kanats?

M. Ayazi. (1) La longueur minimum de chaque kanat est de 1 000 mètres et la longueur maximum de 3 500 mètres.

(2) Le débit total des 30 kanats est de 900 l/s.

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RICE GROWING FOR RECLAMATION OF SALT- AND SODIUM-AFFECTED SOILS IN THE ÇUKUROVA PLAIN

by

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INTRODUCTION

In cropping the irrigated or non-irrigated semi-arid soils of southern Turkey there are two primary soil characteristics to be borne in mind. One of these is the salt concentration of the soil solution and the other is the alkalinity.

The Çukurova plain constitutes an area of approximately 20,000 ha., more or less suitable for irrigation. At the present time most of the cultivated land produces cotton and wheat without irrigation. When irrigated it is assumed that 10–20 per cent of the area will become saline and unproductive because of rising water tables. This has already occurred in an area near the Tarsus irrigation station, where 2 ha. of the land was used for these trials.

OBJECTIVES

The major objective of this investigation was to determine the effects of rice growing on salt- and sodium-affected soils during reclamation and improvement.

REVIEW OF THE LITERATURE

There is an abundance of literature more or less relating to this investigation. Most of the work on the subject has been incidental to other lines of research, such as the study of single ions or of the effect of cultural methods upon salt content.

Much research has been done in this field in various countries. Some results of interest are included at this point.

Young rice is sensitive to the presence of chlorides in water, but the plant develops a resistance as it matures. According to Shutts, the commonly accepted tolerances of rice to salt water are as shown in Table 1.

TABLE 1. Commonly accepted tolerances of rice to salt water

Concentration of salt	Tolerances
ppm.	
600	Tolerable at all stages
1 300	Rarely harmful, and only to seedlings in dry, hard soil.
1 700	Harmful before tillering; tolerable from jointing to heading.
3 400	Harmful before booting; tolerable from booting to heading.
5 100	Harmful at all stages.

Chlorides tended to accumulate in plants and soil when they were grown at a distance of 2–10 m. from a ditch filled with water containing 103,000 ppm. (10.3 per cent) sodium chloride. Increasing concentrations of salt caused a progressively greater reduction in the height, weight, leaf growth and seed number of affected plants [1].[1]

Rice plants were cultivated in a nutrient solution having various levels of Cl. The plants grew to the mature stage in all the plots except those in which the Cl content was 0.8 or 1 per cent; plants in those last plots died at the ear-forming stage [3].

The addition of 0.5 per cent NaCl to rice soil reduced grain formation and germination and slightly decreased straw production [2].

In nutrient *solutions* containing 1.0–2.0 per cent NaCl rice did not grow; both the absorption of H_2O and growth ceased and the blades wilted.

Rice plants tolerate moderately saline concentrations [4].

DESCRIPTION OF SOILS AND LOCATION

The experimental plots were established to the east of Alifaki village near Tarsus, southern Turkey, in the autumn of 1953, in order to reclaim soil that had become highly saline and alkaline (see Plates V, VI and VII).

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[1] The figures in brackets refer to the bibliography on page 294.

The colour of the soil is brownish-grey, developed on nearly level terrain in a semi-arid (534 mm.) mediterranean type climate. The parent materials are strongly, calcareous, fine-textured alluvial deposits. The soils are azonal and have little horizon development except for minor textural differences in the clayey strata and for strongly developed subsoil, much affected by wet and poorly drained conditions.

Chemical and physical analysis of unproductive Alifaki soils

Samples of unproductive soils were collected before the experiments were begun. The results of these analyses are presented in Tables 2 and 3.

A study of the data of individual soil samples invariably shows salt and sodium accumulation. The predominant salts are sodium chloride and sodium sulphate. There is a zone of gypsum accumulation between 36 cm. and 110 cm. Because of the salinity and of the moderately high exchangeable sodium percentages these samples are classified as calcareous saline-alkali.

The reclamation of these soils depends on: (a) the removal of excess soluble salts; (b) the removal of excess adsorbed sodium.

After the drainage problem has been solved satisfactorily, leaching is the only economical method known in world agriculture whereby the excess of soluble salts may be removed from the soils. For this process to be successful, good quality irrigation water is the first essential. Table 4 gives the analysis of the irrigation water used.

The removal of excess adsorbed sodium is accomplished by substituting calcium for sodium in the soil and then removing the sodium by leaching. Gypsum is used as the source of available calcium simply because it is cheap.

TABLE 2. Analyses of unproductive Alifaki soils

Laboratory accession no.	Depth	Percentage of water in air dry condition	The analyses of soils from Tarsus Plain					Exchangeable-cation			Status Ca + Mg	meq./100 gr. soils	
			Per cent water at	$CaCO_3$	Gypsum	Organic matter	Saturation paste	CEC	Na	K		Na	K
	cm.			%	%	%	*p*H					%	%
5319[1]	0–15	6.38	61.7	28.1	0.36	2.00	7.34	31.6	6.30	1.21	24.1	19.9	3.8
539	0–15	6.13	67.0	28.9	0	1.86	7.50	30.1	7.62	1.04	21.4	25.3	3.5
5310	15–46	4.78	82.3	35.3	0	0.83	7.75	32.4	7.58	0.53	24.3	23.4	1.6
5311	46–71	6.25	84.2	36.9	4.3	0.28	7.79	27.4	7.88	0.41	19.1	28.8	1.5
5312	71–107	5.93	87.3	33.0	0	0.41	7.87	27.2	5.96	0.59	20.6	21.9	2.2

1. The mixed surface soil sample.

TABLE 3. Analyses of unproductive Alifaki soils

Laboratory accession no.	Depth	Soluble ion concentration in saturation extract meq./l.										$EC_{25}10^3$	Permeability
		Ca	Mg	Na	K	Total cation	CO_3	HCO_3	Cl	SO_4	Total anion		
	cm.												
5319[1]	0–15	159	170	239	1.2	569	0	2.1	514	41.3	557	45 900	Low
539	0–15	111	142	273	1.0	527	0	2.1	463	36.3	501	42 400	Low
5310	15–46	33.4	67.9	193	0.4	294	0	2.8	249	32.6	284	26 100	Low
5311	46–71	74.8	92.0	230	0.5	397	0	0.8	298	59.7	369	31 400	Low
5312	71–107	32.2	67.9	235	0.4	335	0	1.2	274	29.8	305	27 600	Low

1. The mixed surface soil sample.

TABLE 4. Water analysis

Laboratory accession no.	Name of river	*p*H	$EC_{25}10^6$	Composition meq./l.											Irrigation class	Hazard	
				Na^+	K^+	Ca^{++}	Mg^{++}	Total cations	CO_3^{--}	HCO_3^-	Cl^-	SO_4^{--}	Total anions	Na		Salinity	Sodium
														%			
518	Seyhan river	7.90	400	0.54	0.01	1.90	2.15	4.60	0	1.80	3.00	—	4.90	11.7	1	moderate	negligible

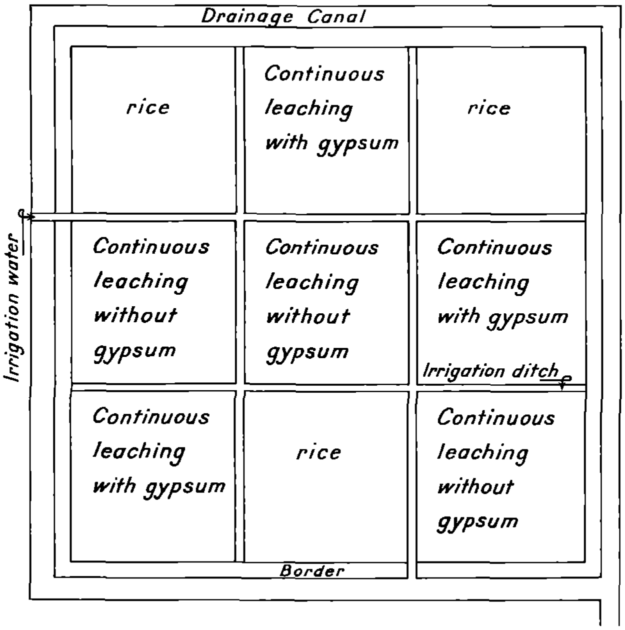

FIG. 1. Block design for treatments.

Owing to its high $CaCO_3$ content, the reclamation of this soil is possible by leaching only (without gypsum), as is simultaneous rice cultivation.

Treatments. (a) Continuous leaching (without gypsum). (b) Continuous leaching, using gypsum. (c) Leaching by rice cultivation.

Method used. Each treatment was replicated three times at random in the block pattern shown in fig. 1.

Results. One measure of the effectiveness of leaching in reclamation is the change in the salt status of the soil. Changes occur in the soluble salt content and exchangeable sodium percentage as a result of leaching, the use of gypsum and rice cultivation.

It will be noted that, before leaching, the soil was high in salt and exchangeable sodium but that these varied with depth. Continuous leaching (without gypsum) greatly decreased the salt concentration at 60 cm. depth. The use of gypsum and rice cultivation greatly decreased the salt concentration at all depths studied and there is a significant difference in replaceable sodium content. For this reason we advocate the cultivation of rice during reclamation; the rice seems to produce an amendment effect on the root system. Such a system produces quantities of carbon dioxide which combine with the alkali to form sodium bicarbonate. These changes may occur as follows:

$$CO_2 + H_2O \longrightarrow H_2CO_3$$

$$H_2CO_3 + CaCO_3 \longrightarrow \underset{\text{Soluble}}{\underline{Ca(HCO_3)_2}}$$

The rice plant also influences infiltration rates. Another most important aspect of this treatment is the economic one. Rice produced an average of 130 kg. of paddy rice dekar: this helps to pay for the construction of drainage canals. In addition, rice stubble supplies organic material to the soil.

RÉSUMÉ

Récupération des sols salins et sodiques par la culture du riz dans la plaine de Çoukourova (B. Öztan et D. Dinçer)

Des parcelles expérimentales ont été constituées près de Tarse en vue de recherches sur les moyens de récupérer des sols devenus fortement salins ou alcalins. Trois traitements par lessivage ont été essayés. Un lessivage continu (sans gypse) a réduit dans de fortes proportions la concentration saline à une profondeur de 60 centimètres. L'emploi du gypse et la culture du riz ont l'un et l'autre diminué la concentration saline à toutes les profondeurs étudiées, et l'on a constaté une différence importante de la teneur en sodium remplaçable. Les auteurs recommandent donc la culture du riz, qui paraît produire sur les racines le même effet qu'un amendement du sol et influer sur les taux de filtration. En outre, la vente du riz ainsi produit contribue à couvrir les frais de construction des canaux de drainage, et le chaume du riz enrichit le sol en matières organiques.

DISCUSSION

G. AUBERT. L'orateur peut-il nous donner une idée de la quantité de gypse utilisée ainsi que de celle d'eau d'irrigation?

B. ÖZTAN. The quantity of gypsum used was 200 kg./ha. or approximately 1,600 lb./acre, and 2 × 4 m. irrigation water applied during two years.

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THE IMPORTANCE OF BIOLOGICAL FACTORS IN THE IMPROVEMENT OF SALINE SOILS

by
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The danger of salinization in irrigated agricultural land is known to be one of the biggest problems in bringing arid lands under cultivation. In West Pakistan, nearly as much land is lost every year by salinization as is reclaimed for agriculture.

The salinization of irrigated land can occur in two ways: (a) the irrigation water does not penetrate sufficiently deeply into the soil, and most of it evaporates; (b) as a result of irrigation, the level of the ground-water rises, bringing the ground-water within the capillarity range; thus the ground-water is drawn up by capillary action and evaporates.

Rain-water, as is known, contains no mineral salts; however, all irrigation water having its source in the soil leaves mineral substances in the soil when it evaporates. Often, moreover, in arid zones the irrigation water is itself slightly saline, hence as a result of evaporation the concentration of salt in the soil may be increased to such an extent that salt crusts are formed.

In irrigation areas where there is a risk of salinity, it is expecially important to take suitable precautions in advance.

Reducing the evaporation by all possible means, as for example: (a) shelter belts, or for shorter distances, hedges, to reduce air movements; (b) cultivation of perennial crops or, if annual crops are cultivated, introduction of fill-in crops so that the ground is protected for as long as possible.

As fig. 1 shows, the evaporation from unprotected soil is much higher than that from protected soil.

Reducing and interrupting capillary action in the soil, for example, by general improvement of the soil structure, especially by improving the structural stability (e.g. stability of the aggregates of the soil to water) by organic manuring. The organic material should, however, not be ploughed in too deeply, but should be worked into the top soil, after the manner of natural vegetation, since the micro-organisms can then develop satisfactorily (see Plate VIII). Soils that have become compact by addition of water, and have formed crusts with cracks, have much higher capillarity than has a good soil whose aggregates are stabilized by micro-organisms (see Plate IX).

The use of mineral fertilizers is a special problem in relation to soils liable to salinization. A satisfactory lime content is, as is known, important not only for the structure and chemistry of the soil, but also for the plants themselves. It is usually assumed that cultivated soils in irrigation areas contain sufficient lime, since the *p*H is mostly between 7 and 8. This rather high *p*H may, however, also be due to the presence of sodium and potassium ions, since those substances are more mobile than lime and can rise more easily to the surface. An examination of a salt efflorescence from the Indian Punjab gave a content of 16.4 per cent NaO and only 3.7 per cent CaO. Apart from this, the lime may be non-uniformly distributed in the soil, and/or may occur in the form of large concretions.

Lime fertilization as a precaution is seldom used in soils threatened with salinization. Also, only lime-free nitrogenous fertilizers such as ammonium sulphate are normally used. Therefore, investigations should be made to determine whether there is a decrease in the amount of available lime in the root zone over extended periods of cultivation.

From the plant physiological point of view, lime has just the opposite effect from sodium on the cell plasma. It can therefore balance out the harmful effects of sodium by ionic antagonism. In relation to magnesium also lime has an antagonistic effect. In saline soils especially, therefore, an adequate amount of available lime is very important for the growth of the plants.

In strongly saline soils where precautions have not been taken in time the only possible way of removing the salt is by leaching. Often, however, the difficulty arises that the water cannot penetrate sufficiently deeply into the soil. In sodium-containing clay soils, for example, water cannot penetrate; it remains on the surface and evaporates without performing any useful purpose. Rice-cultivation experiments involving leaching carried out in Hungary before the end of the war showed,

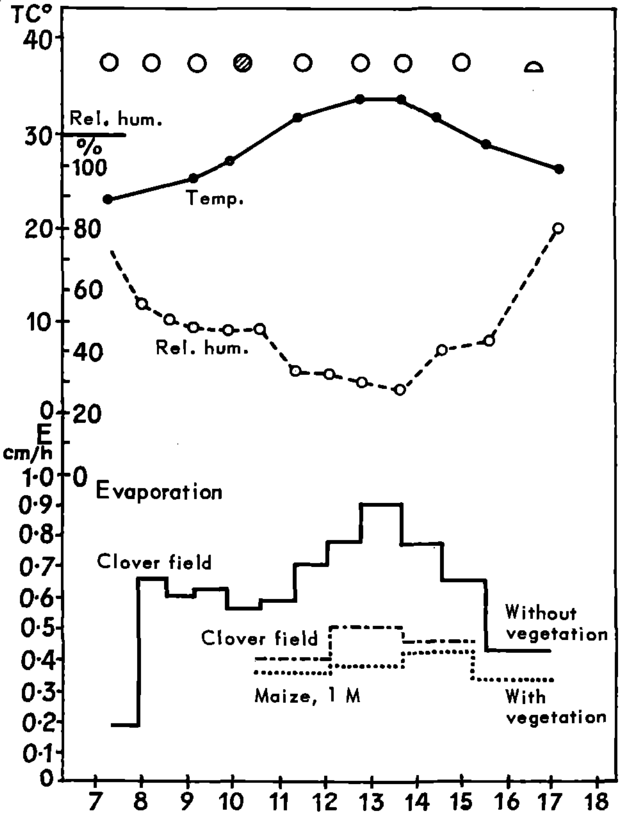

FIG. 1. Evaporation on the soil surface with and without vegetation.

however, remarkable success, as the following description indicates.

In the Hungarian alkali-steppes, conditions are extremely unfavourable by reason of the combination of a dry climate and a sodium clay soil of high alkalinity and very poor structure and water dynamics. When dry the soil is stone-hard. When water is added it cannot penetrate. Experiments to leach out the salt by constructing fish ponds consequently failed completely. After 30 years a layer of salt-free mud of 15–20 cm. thickness developed, but the original salt beneath it was unchanged and, because of the high capillarity, the mud again became saline when the pond water was removed.

On the other hand, when rice is cultivated, the soil, already under water, is ploughed; only by such working of the soil is it made possible for the water to penetrate sufficiently deeply into these black alkali soils. Since the rice-field remains under water, the leaching process can be very thorough. Before harvesting, the water is drained off and the salt removed with it. With extremely bad soils, the water is renewed twice or thrice during the growth of the crop. It must be emphasized that the leaching does not reach beyond the depth of ploughing.

As Table 1 shows, even soils with extremely poor clay structure and high alkalinity can be leached by rice cultivation. In regions where the amount of available irrigation water is inadequate, areas for leaching may be selected and dealt with in turn.

TABLE 1. Diminution of salinity on cultivating rice

Soil depth	Original salt content	Percentage of soil salts after cultivation of rice		
		1 year	2 years	3 years
cm.	%			
5–10	1.78	0.29	0.20	0.13
30–35	0.70	0.48	0.29	0.10

The washing out of the soil salts, however, is only the first step. Rice leaves the soil in a waterlogged condition, and there is a danger of salt deposits forming anew on the soil surface because of the strong capillary movement resulting from the increased evaporation in arid climates. After rice cultivation is stopped, the chemical and biological improvement of the soil, together with evaporation control measures, should be started without delay. On no account must the soil be left fallow, because after a few years it would be in a much worse condition than previously.

The biological improvement of the soil, which is of as much importance as the chemical treatment, since it controls porosity, aeration and water movements, begins to take effect. Although the rice roots and stubble form a certain amount of humus in these biologically sterile soils, applications of manure or other organic humus-producing fertilizers are necessary.

Excessive evaporation from the soil is best controlled by the plants themselves, perennial densely growing forage plants being particularly suitable. In Hungary, for example, a crop rotation in which rice was followed by *Lolium italicum* and *Trifolium lodi* gave good results.

As pointed out in this short note, plants are of great importance not only in the precautions against soil salinization, but also in the treatment after leaching. In various arid zone countries plants with a fairly high salt tolerance have been found; for example, various salt grasses and *Atriplex* species. It is desirable that knowledge of such plants should be widely disseminated, so as to encourage improved crop rotation in the areas leached by rice cultivation. Salt-tolerant trees and shrubs are also required for shelter belts.

Obviously, the type of rice used when cultivating for leaching must have the highest possible salt tolerance. Crops, such as rice, growing in water do not encounter high salt concentrations, but the roots may suffer damage caused by high *p*H values if they penetrate more deeply into the soil than the depth of working. The upper limiting *p*H value for the two Turkestan rice species used in Hungary, *dunhan shali* and *varsan-hely,* was 9.5. Since then, other salt-tolerant rice species have been found in other countries.

This short note has therefore one further object, to stimulate scientists of all arid zone countries to prepare lists of salt-tolerant plants on the basis of their own experience. The lists should give the following information: salt-tolerant types or *local types* of various crop species; salt-tolerant forage plants; salt-tolerant species of the natural vegetation which may also have a certain forage value; salt-tolerant trees and shrubs suitable for shelter belts; salt-tolerant species suitable for erosion control.

Information given should include not only the *p*H and salinity limits, but also, in the case of wild plants, the water conditions of the habitat.

RÉSUMÉ

Importance des facteurs biologiques dans l'amélioration des sols salins (G. Repp)

Le risque de salinisation des terres irriguées est l'un des plus importants problèmes que pose la mise en culture des régions arides. Dans un cas typique, il a été démontré que, même dans les conditions les moins favorables — sols argileux très alcalins (contenant du $NaCO_3$) et de structure très médiocre — le sel peut être lixivié en trois ans par la culture du riz. Mais, pour obtenir des résultats définitifs, il faut, immédiatement après cette culture, améliorer le sol du point de vue chimique et biologique et le replanter en temps opportun afin de réduire l'évaporation à la surface. Il est recommandé d'établir pour chaque pays une liste des variétés locales de plantes vivrières, fourragères et sauvages résistant à la salinité du sol.

DISCUSSION

A. Molenaar. (1) Dr. Repp suggests that loosening of the soil surface, as is practised in California, reduces or interrupts capillary action in the soil. I should like to inquire where in California the soil is loosened for this specific purpose, and whether Dr. Repp has any data to show the effectiveness of this practice?

I ask these questions because research workers at the Agricultural Experiment Station at Davis, California, generally are in agreement that the effectiveness of creating a soil mulch by cultivation is very limited, especially where irrigation water is applied at regular intervals, mainly because the greater part of the water that evaporates in the intervals between irrigations must evaporate before the farmer can get into the field to cultivate. Cultivation does serve another important function, however, and that is the control of weeds which, if allowed to grow, might use a considerable amount of the water applied.

(2) The author has mentioned that evaporation can be reduced by covering the soil surface with a mulch of straw or other dry material. I agree that such would be an effective measure, but I doubt that it can be realized on any extensive scale. I should like to ask Dr. Repp whether she believes that dry material for mulching could be found in sufficient quantities in the countries of the arid zone to apply the measure on any appreciable scale.

G. Repp. (1) I saw this practice in the peach-gardens in the San Joaquin Valley in California, and the reason given was that it controls weeds as well as breaks up the capillarity of the soil.

In Italy irrigated fruit gardens are usually covered with grass, except for small areas around the trees. This grass is used as forage for the cattle and the manure of the cattle is used in the gardens in addition to chemical fertilizers. The biological activity and the humus content of these soils are very good.

According to my comparative investigations, grasses, under the same conditions, do not transpire as much as, for example, clover or deep-rooting weeds.

(2) No. This method is I think possible for limited areas only. Large-scale crop rotation, for example, cultivation of crops like lucerne which cover the soil well and over a long period, significantly reduces the dangerous surface evaporation of the soil. But often the fields are very small, especially in Asia; or, in bigger fields, there occur small areas where the crop growth is very poor or the crop dies because of unequal leaching or locally bad soil quality. In such cases, mulching should be used to cover the soil which otherwise would deteriorate more and more as a result of salt accumulation in the upper levels.

A. K. Khudairi. I should like to ask Dr. Repp a question concerning her suggested addition of lime to counteract the harmful effect of sodium. Wouldn't this be an expensive proposition, since the soluble sodium can be removed by leaching and exchangeable sodium can be removed if sufficient calcium is present in the soil? And did she analyse for calcium to find out if it is in sufficient quantities to remove the harmful sodium?

G. Repp. Yes, anion and cation analyses of my soil samples have been made. Soils in salt steppes even of *p*H around 8.0 contained almost no Ca. Their high *p*H was not based on Ca, but on Na-salts. The sap expressed from different cultivated plants growing in these soils contained 3–10 times more Na than Ca.

In agriculture I think we must consider not only the soil itself, but also, and mainly, the well-balanced mineral nutrition of the plants. After all, the aim of every soil amelioration is to increase the yields. If in soils containing Na-salts the plant-available Ca is deficient, this is a very unfavourable factor for plant growth. Physiological investigations show that Ca is the only element which can balance the Na-damage of the plasma. If there is a lot of Na taken up from the soil, the need for Ca may increase. For example, in the United States a "Na induced Ca-deficiency" was found.

Therefore, in saline soils that are to be ameliorated it is very important to analyse the amount of Ca available. Even in soils with Ca-concretions the plants could suffer from Ca-deficiency due to unequal distribution of the available Ca in the soil.

The methods of ameliorating saline soils by leaching are not comparable to addition of lime. Leaching has to be used in any case in soils in which the salt concentration is high; sometimes it may even be combined with application of gypsum. But very often, owing to lack of drainage, the salts cannot be leached *away* but only leached *down* to deeper levels and the danger of re-salinization exists. In such cases the addition of small amounts of lime would prevent or minimize the damage to the plant, at least for a time. Also, in soils in the first stages of salinization, e.g., in the former Punjab in Pakistan, the addition of Ca would be beneficial.

Nazir Ahmad. (1) For reducing and interrupting capillarity, the author has suggested improvement to the structural stability of soil by manuring. Could deep ploughing not help to do the same job?

(2) The author has connected capillarity with compactness of soil. Is there any relation between capillary height and compactness of soil?

G. Repp. (1) Ploughing and mechanical working of the soil certainly improve its structure temporarily. "Stability of soil structure", however, means that the good structure remains even if water is added. In soils of poor biological activity and poorly endowed with soil micro-organisms, the aggregates formed by ploughing are destroyed quickly with the addition of water. Such types of soil become compact and form crusts on the surface. The capillarity increases and the penetration of water is prevented by evaporation.

The stability of the soil aggregates depends greatly on the presence of soil micro-organisms like bacteria, soil algae, fungi and actinomyceta. The last, especially, are very important for the formation of good humus. These soil micro-organisms help to fix the aggregates formed by chemical coagulation and to increase their size.

Of course these organisms, being mostly heterotrophic, need organic material in the soil for their nutrition. Manuring of saline soils after leaching adds not only the organic matter but also the micro-organisms themselves, which are comparable to a biological inoculation of the soil. This is important since saline soils usually have poor biological activity.

(2) Theoretically yes, because the smaller the diameter of the capillaries the higher is the capillarity effect. In compact soils the capillaries are more numerous and smaller than in non-compact soils. In nature, however, the capillarity is a very complex phenomenon and is influenced by many other factors. For example, plugging of the capillaries with colloidal matter or by hydration, especially in heavy Na-clay soils, may decrease the capillarity; the size and continuity of the soil pores are of course not as good as an ideal capillary tube; air may interrupt the continuity of the water column, etc. Compacting a loam soil may sometimes increase its capillarity by increasing the number of pores of capillary size; if one does the same in a clay soil, the capillarity may decrease as a result of the plugging of the already existing pores of capillary size.

G. Aubert. Dans cette riziculture sur sols salés en Hongrie, a-t-on parfois utilisé des phosphates naturels de chaux au lieu de gypse pour combattre la teneur excessive de ces sols en sodium?

G. Repp. So far as I know, not for that special purpose. Phosphates have been used in the normal fertilizing of the soils with N, P and K after leaching.

ELECTRICAL CONDUCTIVITY RELATIONSHIPS FOR SOIL PASTES AND 1:1 SOIL WATER SUSPENSIONS AND THEIR EXTRACTS

by

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INTRODUCTION

The measurement of the electrical conductivity (specific electrical conductance)[1] of a salt solution is a convenient and fairly accurate method for the estimation of the salt content of that solution, provided the concentration is not too high, perhaps not much higher than 10 per cent. The method has thus been found very useful in the appraisal of soil salinity, since a measurement of the electrical conductivity of a portion of a known quantity of an extract of a known quantity of the soil can be readily made. This method is, moreover, now rather extensively used for the appraisal of soil salinity with respect to plant response [4].[2] For this purpose the electrical conductivity of an extract of a saturated soil paste[3] is determined and expressed in millimhos[4] per centimetre, and converted to its equivalent at the standard temperature of 25°C. When the conductivity of this extract, the saturation extract, is above 4 mmhos/cm., then the soil is saline with respect to most crops and is classified as a saline soil. This method is recommended [4, pp. 8–9] as a general method for appraising soil salinity in relation to plant growth, except in the case of coarse-textured soils.

The estimation of the salt content of a soil from a measurement of the electrical conductivity of an extract of that soil is, however, time-consuming, since the extract has first to be obtained and this usually requires filtration with the aid of a vacuum pump. This involves extra labour and requires relatively large quantities of soil in order to obtain a sufficient amount of the extract. Moreover, if the determination is made on the saturation extract, then an additional measurement has to be made, namely the ratio of water to soil in the saturated paste. For these reasons and because of the possibility of arriving at results of theoretical importance, it has been found desirable to investigate whether a correlation exists between the electrical conductivity of a soil paste or suspension and its extract, so that the estimation of the soil salinity could be made directly from a measurement of the electrical conductivity of the soil paste or suspension and a knowledge of the salt content of an extract when its electrical conductivity is known. This last correlation is well established for extracts from many soils in the United States [4, p. 84], but had also to be investigated in the work discussed here.

With the above aims in view, 200 soil samples, representing the whole range of textural composition from sand to clay and collected from a number of areas in central and southern Iraq, were selected for the investigation. The measurements taken included the electrical conductivities of the saturated soil paste and the 1: 1 soil to water suspension and their extracts, the saturation percentages for all 200 samples, and the total dissolved salts in the 1: 1 extracts of 170 of these samples.

METHOD

The soil samples used in this work were oven-dried for 12–24 hours at a temperature of about 105° C. The samples were subjected when dry to machine grinding, which adjusted the maximum particle size to about 2 mm. The ground samples were then used as such, i.e. without sieving, for all the tests covered by this work.

The saturated pastes were prepared in accordance with the method described by the U.S. Salinity Laboratory staff [4, p. 84, Method 2]. The weight of soil used for the preparation of the paste and the 1: 1 suspension was 100 grammes. The required amount of water was added from a measuring cylinder and the weight was taken to be numerically equal to the volume. The pastes and the suspension were allowed to stand for about one hour before the conductivity measurement was made. The soil water extracts were obtained from the pastes and suspensions by filtration, under vacuum, almost immediately after the conductivity measurements of these pastes and suspensions had been made.

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1. What is really measured is the electrical resistance of the solution, but the measuring instrument is calibrated to give the electrical conductivity instead.
2. The figures in brackets refer to the bibliography on page 303.
3. See under "Method".
4. The mho. is the reciprocal of the ohm.

The electrical conductivity of the extract was measured, in a series of preliminary experiments, using an Industrial Instruments conductivity bridge, model RC-12 CIP, in conjunction with either an Industrial Instruments soil cup, model CEL-M, or a glass micro dip type conductivity cell with platinized platinum electrodes ("Soiltest", model A-58). In other preliminary experiments a Mullard conductivity bridge type E7556 was used in conjunction with either of the above-mentioned conductivity cells. It was found that a combination of the Mullard conductivity bridge and the glass micro dip gave the most systematic results and the best check with standard solutions of known conductivities, for the whole range from 1–120 mmhos/cm. Also, this combination gave a very sharply defined balance point, as indicated by the magic eye. This same assembly was also found to give the best results and the sharpest balance points when used for the determination of the conductivities of the pastes and 1 : 1 suspensions. The other combinations of bridge and cell failed to give a sharp balance point when used for the measurement of the EC of pastes and suspensions, especially when the EC was greater than a few millimhos per centimetre even when a variable condenser, to balance out the capacitance effect in the test cell, was used. The use of the glass dip cell for the measurement of the EC of saturated pastes is, however, not altogether convenient, since—and especially when the soil is heavy-textured—good care must be taken to avoid the trapping of air bubbles between the electrodes; moreover the cleaning of the inside of the cell is somewhat time-consuming.

The saturation percentages were determined for all of the 200 samples by adding distilled water from a measuring cylinder to 30 grammes of soil, until a saturated paste was formed. The cup containing the paste was covered to reduce evaporation and the paste was left standing for one hour and then re-examined. Water or soil was then added to the paste when it was judged necessary.

The salt content of the extract (total dissolved salts) was determined for the 1 : 1 extracts by evaporating to dryness 10 ml. aliquots of the extracts. For the purpose of this determination, the extracts were always refiltered when they were not very clear. No determination of the density of the extracts was made and the density was assumed to be 1 gm./cc. for the purpose of calculating the percentage of dissolved salts in the extract.

In all the above measurements in which the weight of the soil was involved, no correction was made for the small amounts of moisture absorbed by the soil after oven-drying.

RESULTS AND DISCUSSION

It may be appropriate, before presenting the results of this work, to give an idea of the general properties of the soils used in the investigation. These soils, which well represent the soils of central and southern Iraq, are calcareous, lime being present in concentrations usually varying from 25 to 35 per cent. On the whole, these soils are highly saline. If the criterion for an alkali soil is taken to be an exchangeable sodium percentage in excess of 15, then most of these soils would be classified as saline-alkali soils. The soil reaction is invariably alkaline, the *p*H ranging from 7.2 to 8.4, with the value of 7.7 being the most probable average. The predominating single salt in these soils is sodium chloride. Gypsum is very frequently present in varying concentrations, sometimes amounting to 20 per cent on a dry weight basis. When the mechanical analysis is performed without the removal of lime by acid treatment the apparent texture is predominantly silty clay, silty clay loam and clay. When the lime is removed then the texture tends to be even heavier.

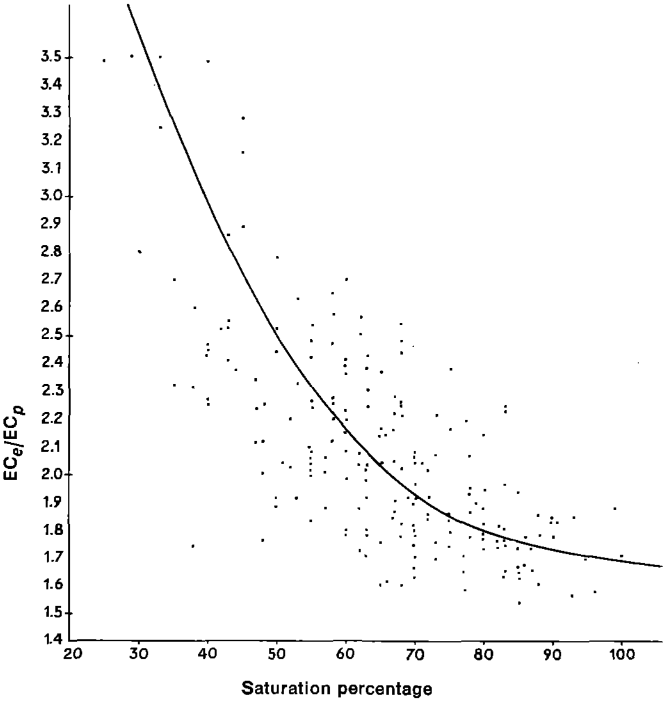

FIG. 1. Relation between the ratio EC_e/EC_p and the saturation percentage.

A preliminary examination of the results of the electrical conductivity measurements for the saturated pastes and the saturation extracts showed that no simple and direct relation existed between the electrical conductivity of the saturated paste (EC_p) and that of the saturation extract (EC_e). However, it was found that when the saturation percentage (SP) was taken into consideration the ratio EC_e/EC systematically increased as the SP decreased. The ratio EC_e/EC_p was then plotted against SP and the resulting plot is shown in fig. 1. It may be seen that the ratio is more than doubled as the SP decreases from 100 (corresponding to very heavy-textured soils) to 30 (corresponding to coarse-textured soils). The greatest concentration of points on the graph occurs between SP = 60 and SP = 70, where the ratio EC_e/EC_p

is about 2. The curve may be expressed, in the range from SP = 40 to SP = 100, by the approximate empirical equation

$$\frac{EC_e}{EC_p} = 1.7 + 3\left(\frac{100 - SP}{100}\right)^2 \qquad (1)$$

A more accurate equation, describing the curve, is the following:

$$\frac{EC_e}{EC_p} = 6.38 - 0.131\,(SP) + 1.22 \times 10^{-3}\,(SP)^2 - 3.75 \times \times 10^{-6}\,(SP)^3 \qquad (2)$$

The conclusion—that there is no simple and direct relationship between EC_e and EC_p, independent of the nature of the soil—agrees with results obtained by several other workers. Bower [4, p. 16] finds that, for a group of soils from the western states of the United States, equilibrated with various concentrations of a 1 : 1 mixture of sodium and calcium chlorides, the electrical conductivities of the saturated paste and the saturation extract are related by the equation

$$EC_e/EC_p = 5.4 - 0.07\,(SP)$$

where SP = saturation percentage.

This equation agrees with equation (1) only for values of SP below 40, corresponding to coarse-textured soils. Obviously, for SP values greater than about 77 the above equation cannot be used, since EC^e/EC_p then becomes negative. Bower also concludes that there is no easy method for simplifying the relation of EC_e to EC_p. Reitemeier *and Wilcox [1] found that the relation between* EC_e and EC_p was influenced not only by the saturation percentage but also by variations in the salinity and the conductivity of the soil minerals. The present work confirms these authors' findings only with respect to the influence of the saturation percentage on the EC_e–EC_p relation. Turton [3] determined EC_e and EC_p for over 200 soil samples from one area in southern Iraq, and has concluded that the ratio EC_e/EC_p was influenced by the soil texture and that for practically all the tested samples the ratio EC_e/EC_p ranged from about 1.5 for clays to about 3.2 for sands. These limits are in close agreement with those found in the present work.

The electrical conductivity of the 1 : 1 extract (EC_e1) was plotted against the conductivity of the 1 : 1 suspension (EC_s1), and the resulting plot is shown in fig. 2. Some of the points were not shown on the graph because they coincide with points already shown. It may be seen from fig. 2 that a straight line with a slope of 1.74 and passing through the origin fits the data very satisfactorily. Thus EC_e1 is related to EC_s1 by the simple equation

$$EC_e1 = 1.74\,EC_s1 \qquad (3)$$

This relationship is at least valid for EC_e1 values ranging from 1 to 28 mmhos/cm., corresponding to salt contents of about 0.1–2.4 per cent of the dry soil. Below and above these limits, respectively, equation (3) may still hold for further ranges, but it is felt that there are not sufficient points to justify the application of equation (3) to ranges beyond the above-mentioned limits. However, it appears from fig. 2 that equation (3) is at least a good approximation of the relationship between EC_e1 and EC_s1 even up to EC_e1 values of about 50 mmhos/cm., corresponding to a salt content of over 4 per cent of the dry soil.

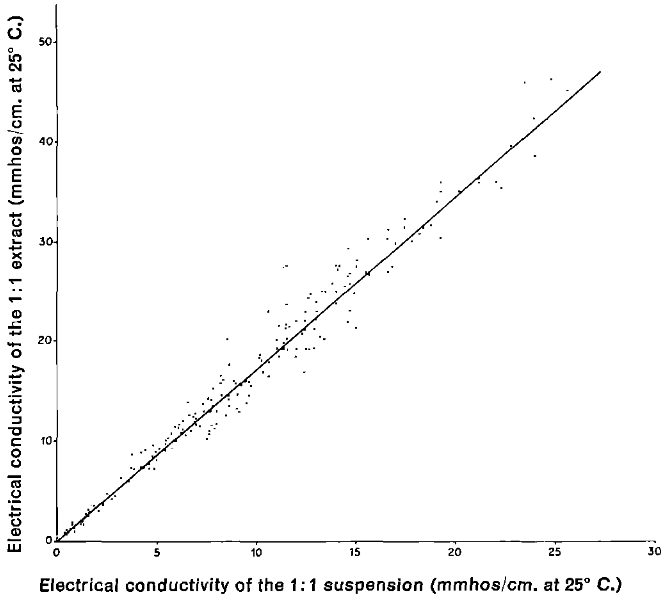

FIG. 2. Relation between the electrical conductivity of the 1 : 1 suspension and that of its extract.

The obvious conclusion which could be drawn from fig. 2 is that the simple relation between EC_e1 and EC_s1 is independent of: (a) the saturation percentage and, therefore, of the texture of the soil; (b) the salt content of the soil, at least in the range of 0.1–2.4 per cent; and (c) the location from which the samples have been collected.

An interesting point is revealed when figs. 1 and 2 are compared. From fig. 1 it is seen that the ratio $\frac{EC_e}{EC_p}$ decreases as the saturation percentage increases until at a saturation percentage of 100 (corresponding to a soil-water system of 1 : 1), the ratio $\frac{EC_e}{EC_p}$ becomes equal to about 1.7. This value is not significantly different from 1.74, the slope of the EC_e1-EC_s1 plot (fig. 2). In other words, as long as the water : soil ratio is 1, equation (3) is applicable no matter whether the soil-water system is a suspension or a saturated paste. Now it seems that the only thing in common between a saturated paste of a clay of SP = 100 and a 1 : 1 sand suspension is that the volume fraction of the soil particles is the same in both systems (about 0.27), since the particle density for the soils of central and southern Iraq is about 2.7 ± 0.05 [2], and appears to be independent of the mineralogical nature of the particle. It thus seems that the extent to which the EC of a solution of an electrolyte is affected by the presence of soil particles depends on the volume fraction of the soil particles, and that differences in the mineralogical nature and physical properties of the particles, such as differences in surface area and electrical properties, are either insignificant or cancel out.

The results of the 170 determinations of total dissolved salts were plotted against the EC of the respective extracts and the resulting plot could, at least in the range of EC = 1 to EC = 20 mmhos/cm., be satisfactorily represented by a straight line described by the equation

$$\text{Per cent dissolved salts} = 0.085 \times \text{EC} \qquad (4)$$

with the EC expressed in mmhos/cm. An assumption made here which is not strictly correct is that all of the solid residue obtained by evaporating the soil extract to dryness is composed of salts only. In fact, this residue also contains varying small amounts of precipitated colloids. The plot of per cent dissolved salts against EC is not reproduced in this publication.

For soils from widely separated areas in the western United States, the plot of the salt content of the saturation extract, expressed in meq./l., against the conductivity, expressed in mmhos/cm., is almost linear with an average slope of about 12 in the range of EC = 1 to EC = 30 mmhos/cm. [4, p. 10, fig. 4]. In the present work, the slope of the corresponding plot is about 14. The slope of the curve in the case of the soils from central and southern Iraq is thus higher than the corresponding one for the soils from the western United States. This is probably because the soils of Iraq usually contain relatively large concentrations of calcium and magnesium sulphates, which would agree with the observation made by the authors of the work on the American soils, referred to above, that soils represented by points that are considerably above the average line usually contain a relatively high amount of calcium or magnesium sulphate.

When equations (3) and (4) are combined, the following expression for the total dissolved salts in the 1 : 1 extract, in terms of the electrical conductivity of the 1 : 1 suspension (EC_s1), is obtained

$$\begin{aligned}\text{Per cent dissolved salts in } 1:1 \text{ extract} &= 0.148\ EC_s1 \\ &\simeq 0.15\ \ EC_s1 \quad (5)\end{aligned}$$

Assuming that the 1 : 1 extract contains all the soluble salts originally present in the soil, equation (5) may be written

$$\text{Per cent soluble salts in soil} = 0.15\ EC_s1 \qquad (5a)$$

Considering that equation (4) may not be applicable when the EC of the extract considerably exceeds 20 mmhos/cm., corresponding to about 2 per cent dissolved salts, it is seen that equation (5a) may not be valid beyond this salt content. It may also be concluded that equation (5a) is only applicable when the soluble salts present in the soil are soluble to the extent of at least 2 per cent. For example, gypsum is soluble only to the extent of about 0.25 per cent. Therefore, if gypsum is regarded as a soluble salt, equation (5a) is not applicable when this salt is present in concentrations exceeding about 0.25 per cent. It is also obvious that, for equation (5a) to be applicable, sufficient time should be allowed for the salts to pass into solution and for the suspension to become, as far as possible, uniform when stirred.

It will be seen from the above analysis of the results of this work that the estimation of the soluble salts content of a soil, for general purposes, may be made, conveniently and reasonably accurately, from a determination of the electrical conductivity of the 1 : 1 suspension and the use of an equation similar to equation (5a).

It may now be proposed, on the basis of the following considerations, that this same method be also used for the estimation of soil salinity for the specific purpose of predicting the suitability of the soil for crop production. The method now commonly used for this purpose is based on the measurement of the electrical conductivity of the saturation extract and the use of a salinity scale according to which a heavy- or medium-textured soil would be non-saline with respect to most crops when its saturation extract has an electrical conductivity not exceeding 4 mmhos/cm. at 25° C. It is felt that the following objections, at least, may be made to this method: (a) it is not directly applicable to coarse-textured soils, in that case a modification is suggested by the U.S. Salinity Laboratory [4, pp. 8–9, 88]; (b) it is time-consuming, since it requires filtration under vacuum; (c) it may be of limited applicability, namely to those soils for which the method has been tested.

The validity of the method requires that: (a) the salt content of the saturation extract, of medium-textured and fine-textured soils, be a constant fraction of the salt content of the soil solution at the lower limit of the field-moisture range; (b) when the salinity of the soil solution, at the lower limit of the field-moisture range, exceeds a particular value, which presumably corresponds to about 16 mmhos/cm. [4, pp. 8–9 and Table 1], then the soil is saline in relation to the growth of most crops, irrespective of the nature of the soil and the climatic and other conditions. It appears that there are so many variables involved that these two requirements may not be satisfied for very many soils, and that any rigid scale of salinity may have a very restricted applicability.

It may thus be suggested that the saturation extract scale of salinity be replaced by a set of correlations between the EC of the 1 : 1 suspension and plant response, for various crops or groups of crops, various soils and at different field-moisture conditions. Once these correlations have been established they may very likely be found reducible to a much smaller number of somewhat different relationships.

RÉSUMÉ

Conductibilités électriques comparées des pâtes de sol. Les suspensions sol-eau 1/1 et leurs extraits (A. Kamaliddin, M^{lle} B. Sharif et A. Hardan)

Afin d'établir un rapport simple entre la conductibilité électrique de la pâte de sol ou de la suspension sol-eau et de leurs extraits, l'auteur a déterminé la conductibilité électrique des pâtes saturées et de leurs extraits, ainsi que celle des suspensions sol-eau 1/1 et de leurs extraits, pour 200 échantillons prélevés dans différentes régions du centre et du sud de l'Irak et représentant les divers types de textures du sol. Il a également calculé les pourcentages de saturation de ces sols.

Il a constaté — ce qui concorde avec les conclusions de plusieurs autres chercheurs — qu'il ne paraît pas possible d'établir un rapport simple entre la conductibilité de la pâte saturée et celle de son extrait. Toutefois, il est apparu que la conductibilité des mélanges 1/1 est liée à celle de leurs extraits par un rapport simple et linéaire, pour tous les types de textures et pour des teneurs en sels variant de 0,1 % à 2 % environ. Ce rapport est indépendant de la région où l'échantillon considéré a été prélevé.

L'auteur a étudié, en outre, les rapports entre la conductibilité électrique de la solution de sol et la quantité totale de sels dissous. Il est parvenu à des résultats analogues à ceux qui sont mentionnés dans les études relatives aux extraits de mélanges d'eau et de sol faites dans d'autres parties du monde. En combinant ce rapport avec celui qu'on obtient pour la suspension 1/1 et son extrait, il est possible d'évaluer la teneur du sol en sels solubles par une méthode simple comportant une seule opération de mesure.

L'auteur traite enfin de la possibilité d'utiliser la conductibilité de la suspension 1/1 comme indice de la salinité du sol au point de vue des réactions des plantes au lieu de faire porter les expériences sur des extraits de pâte saturée, comme il est recommandé dans l'*Agriculture Handbook* n° 60 du Département de l'agriculture des États-Unis [4].

DISCUSSION

N. Ahmad. During extraction we get all the soluble salts in the water, but in the case of paste insoluble salts are there and this can cause a change in conductivity. Is not the scatter of the points in fig. 1 due to this cause?

A. R. Kamaliddin. The presence of particles of sparingly soluble and insoluble salts in the paste should not significantly affect the results because the contribution of these particles to the electrical conductivity of the paste should be negligible.

The main cause of the scatter of the points in fig. 1 is probably the non-uniformity of the soil solution with respect to the concentration of the salts. Inside the soil crumbs the concentration of the salts varies and its average is perhaps generally higher than in the bulk of the solution. This effect apparently occurs in all the soils used in the present work, but to varying degrees, and hence the ratio EC_e/EC_p is affected to differing extents.

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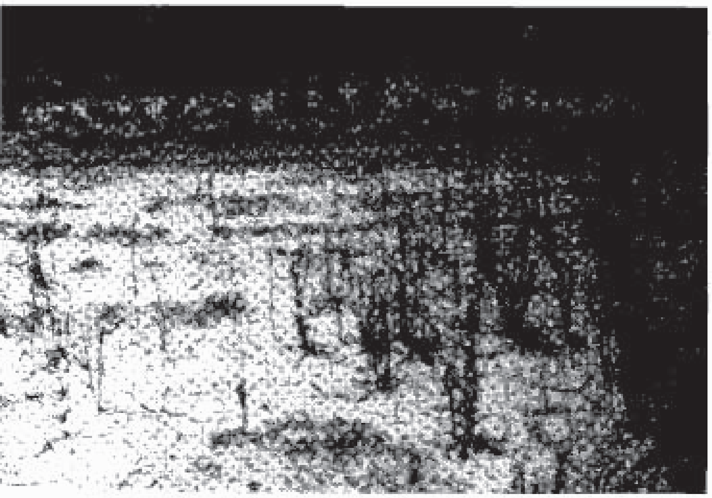
3. Turton, A. G. Private communication, Baghdad, Laboratory of the Directorate of Irrigation.
4. United States Salinity Laboratory. *Diagnosis and improvement of saline and alkali soils*, Riverside, California, 1954, 160 p. (U.S. Department of Agriculture handbook no. 60).

I Surgical preparation of sheep for study of the regulation of body fluids. This photograph shows a Merino sheep with a right-sided parotid fistula of the Wright type. The right carotid artery has been enclosed in a tube of skin. On the left side, a tube of skin contains the carotid artery, jugular vein, and left adrenal gland. The carotid artery has been occluded and the cranial circulation has been diverted to the adrenal transplant by a pneumatic cuff, and the ionic environment of the adrenal gland is being altered by a continuous injection. This procedure permits the study of the influence of change of the chemical composition of the animal's blood upon the hormonic secretions by the adrenal.

Préparation chirurgicale d'un mouton mérinos pour l'étude de la régulation des fluides organiques. La photographie montre, sur le côté droit de l'animal, une fistule parotide du type Wright. L'artère carotide droite est protégée par un manchon de peau. Sur le côté gauche, un autre manchon de peau protège l'artère carotide, la veine jugulaire et la capsule surrénale gauche. L'artère carotide est bloquée et la circulation crânienne détournée vers le greffon par un garrot pneumatique; le milieu ionique de la glande est modifié par infiltration continue. Cette méthode permet d'étudier les effets des variations de la composition chimique du sang sur les secrétions hormonales de la capsule surrénale.

(*Article Denton* et al., *p. 193; photo submitted by the authors / photo fournie par les auteurs.*)



II View of barley growth on one of the checks.

Production d'orge sur une des parcelles témoins.

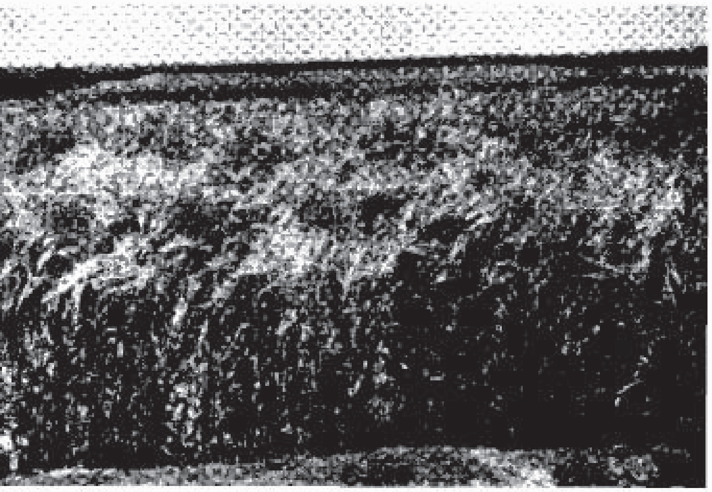
III View of barley growth on one of the plots with 120 cm. leaching.

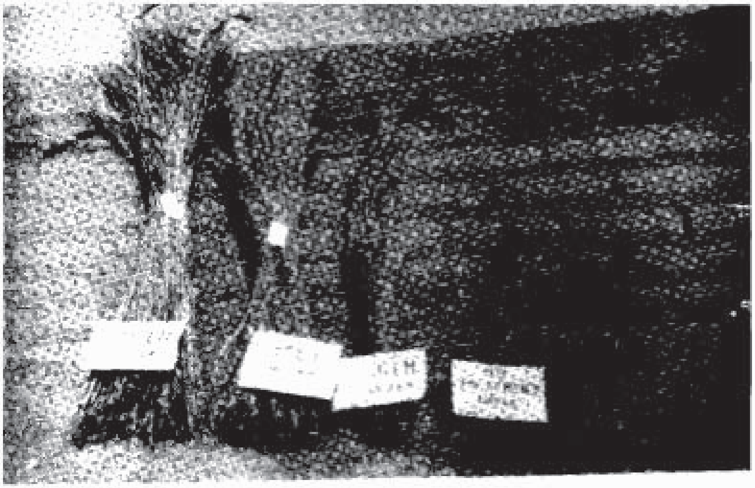
Production d'orge sur l'une des parcelles d'essais après lixiviation sur 120 cm.

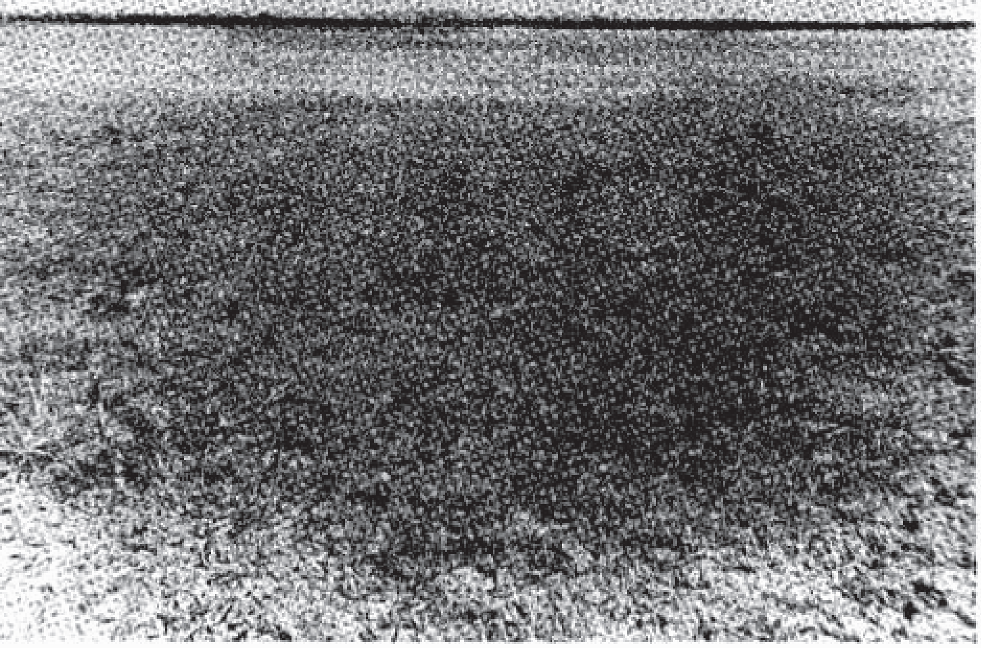
IV Comparison of barley yield from plots with different leaching treatments.

Spécimens d'orge provenant de parcelles soumises à différents traitements par lixiviation.

(*Article Dewan and Bordbar, p. 273; photos submitted by the authors / photos fournies par les auteurs.*)

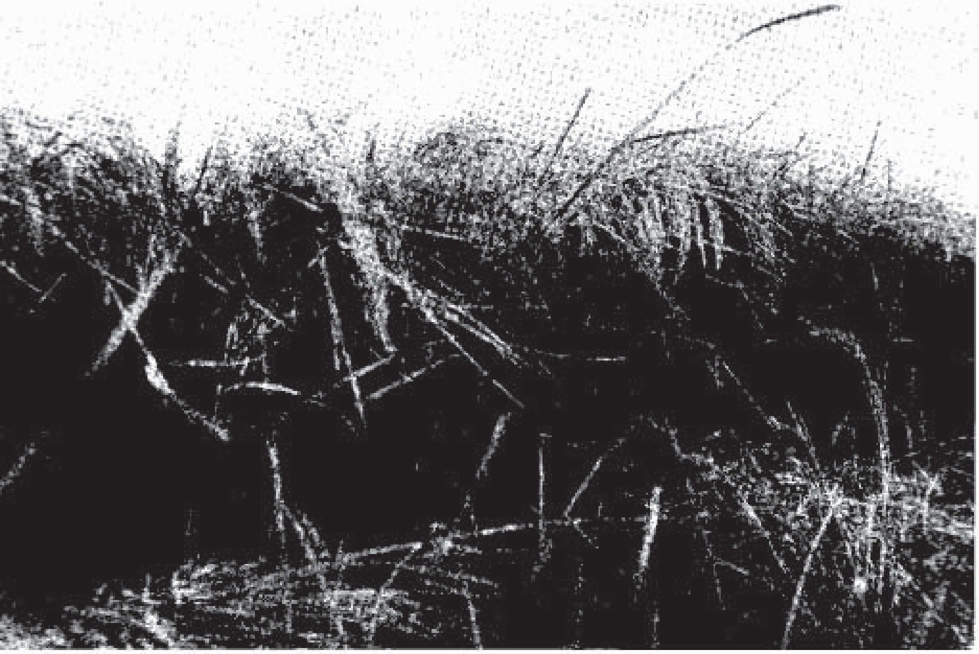






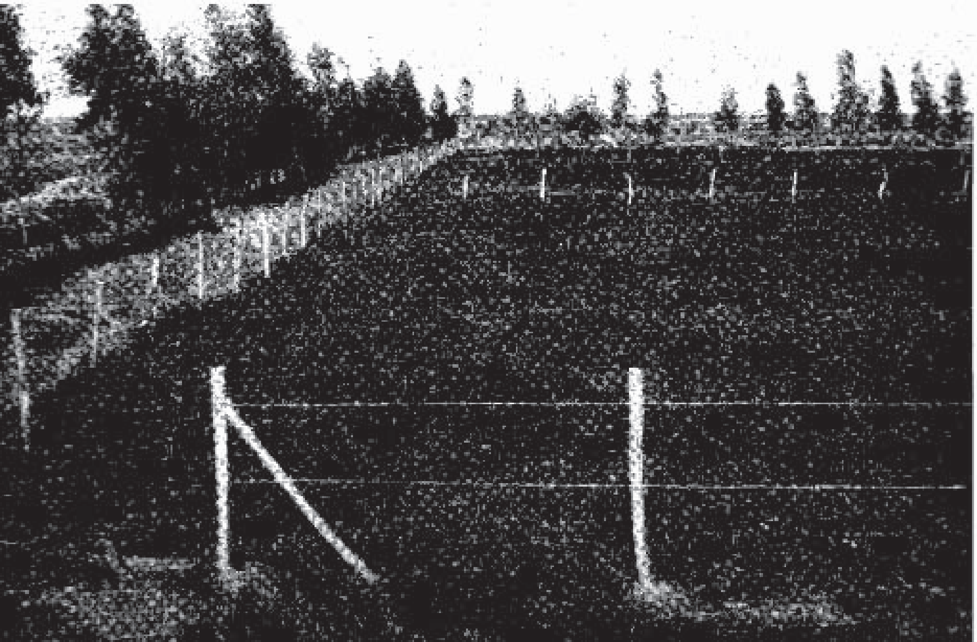
V Before the experiment started.

Avant l'expérience.



VI Rice growing during the experiment.

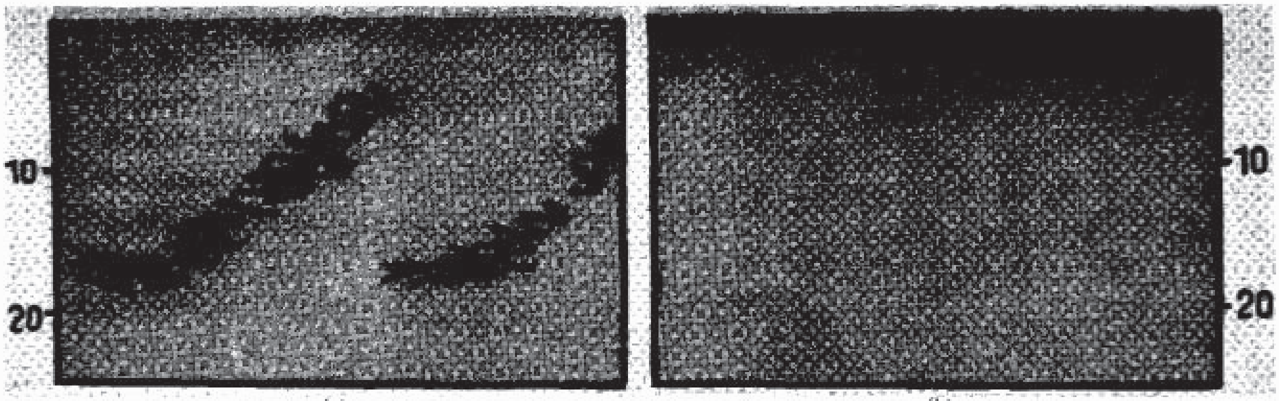
Un champ de riz pendant l'expérience.



VII After two years' leaching of pasture.

Pâturage après deux années de traitement par lixiviation.

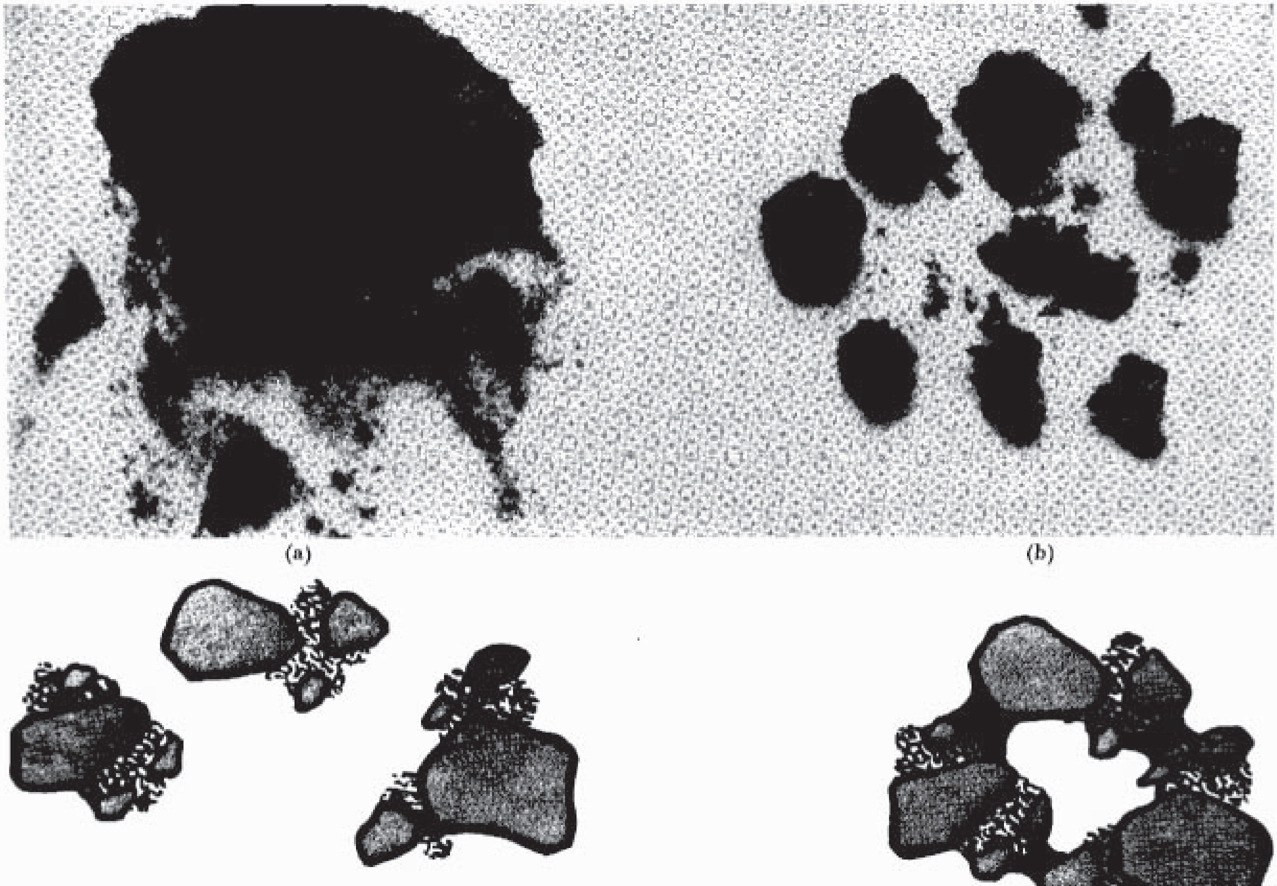
(*Article Öztan and Dinçer, p. 291; photos submitted by the authors / photos fournies par les auteurs.*)



(a) (b)

VIII (a) Manure applied deep in the soil cannot decompose; (b) near the surface, manure decomposes fast, creating favourable conditions for the growth of micro-organisms. (From Sekera, 1954.)

a) Le fumier enterré à une certaine profondeur ne peut se décomposer; *b*) au voisinage de la surface, le fumier se décompose rapidement, créant des conditions favorables au développement des micro-organismes. (D'après Sekera, 1954.)



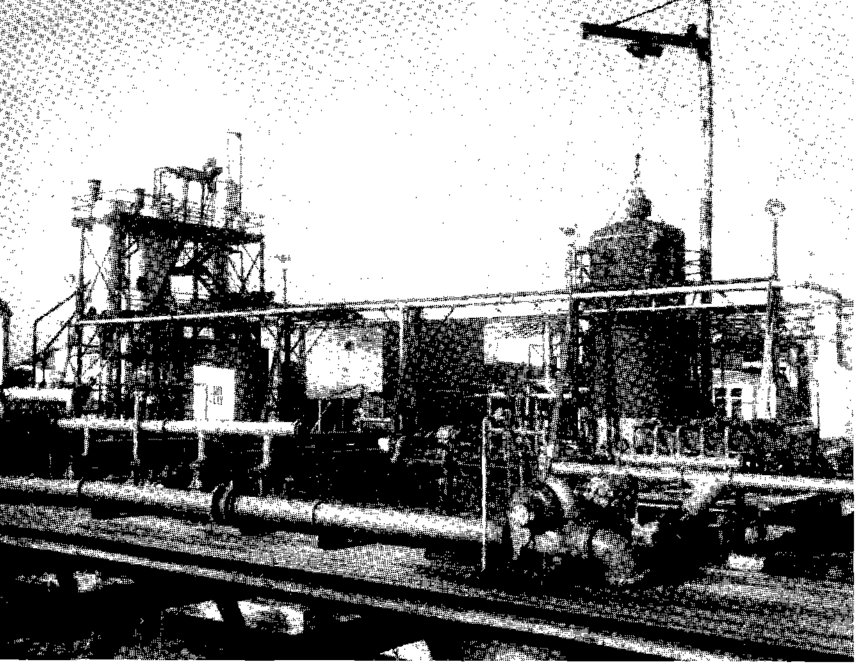
(a) (b)

(a) (b)

IX Water stability of soil aggregates. (a) Without micro-organisms, aggregates turning to mud; (b) with micro-organisms, the soil keeps its loose structure. (From Sekera, 1954.)

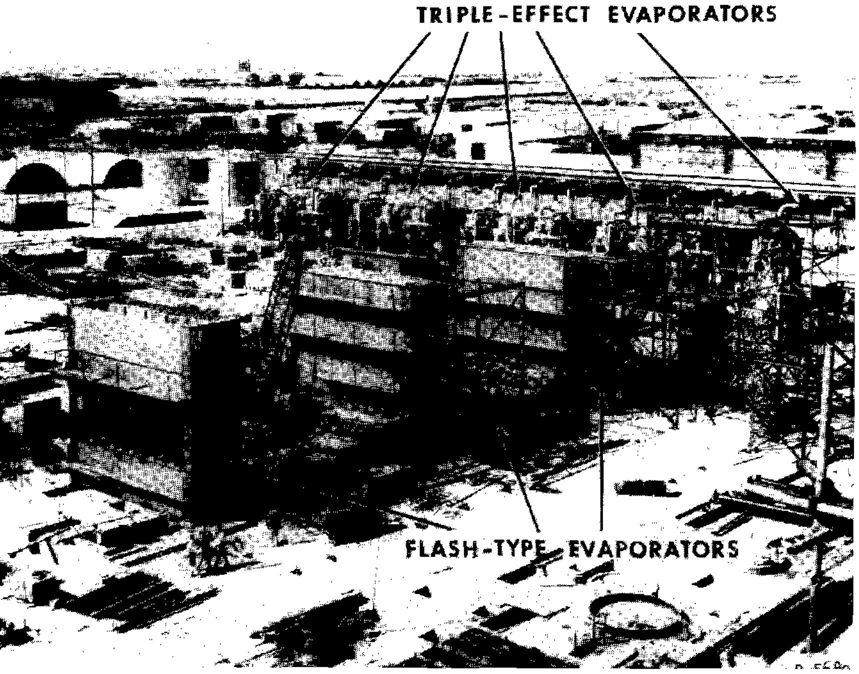
Stabilité des agrégats de sol exposés à l'eau. *a*) En l'absence de micro-organismes, les agrégats se transforment en boue; *b*) le sol qui contient des micro-organismes conserve une structure meuble. (D'après Sekera, 1954.)

(Article Repp, p. 295; photos submitted by the author / photos fournies par l'auteur.)



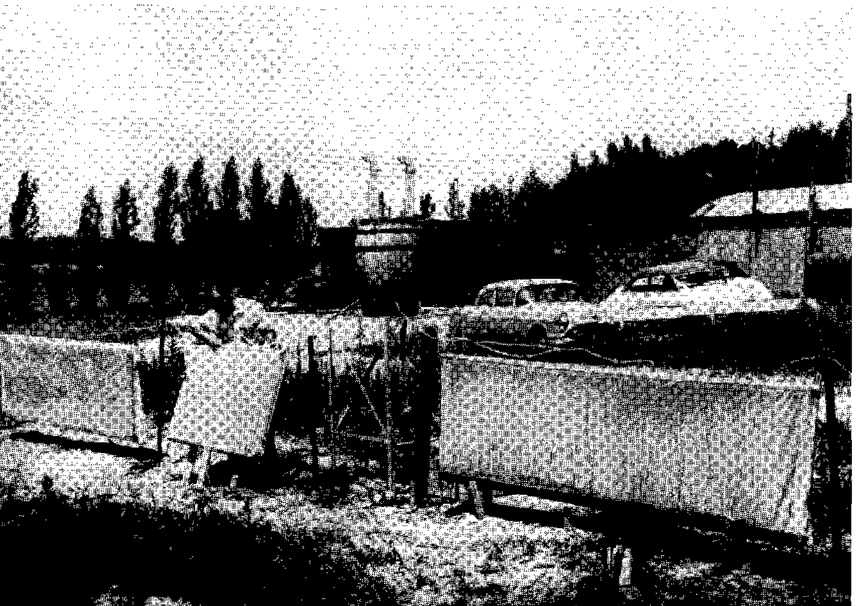
X Pilot plant of W. L. Badger & Hickman Processes at Harbor Island, Wrightsville Beach, North Carolina.

Usine pilote utilisant les procédés W. L. Badger et Hickman à Harbor Island, Wrightsville Beach, Caroline du Nord.



XI Westinghouse electric plant at Kuwait on the Persian Gulf, view showing five triple-effect evaporators (total capacity 600,000 U.S. gallons per day) in operation, and three of four 4-stage flash-type evaporators (capacity of each, 630,000 gallons per day) under construction. (Westinghouse Electric Corp.)

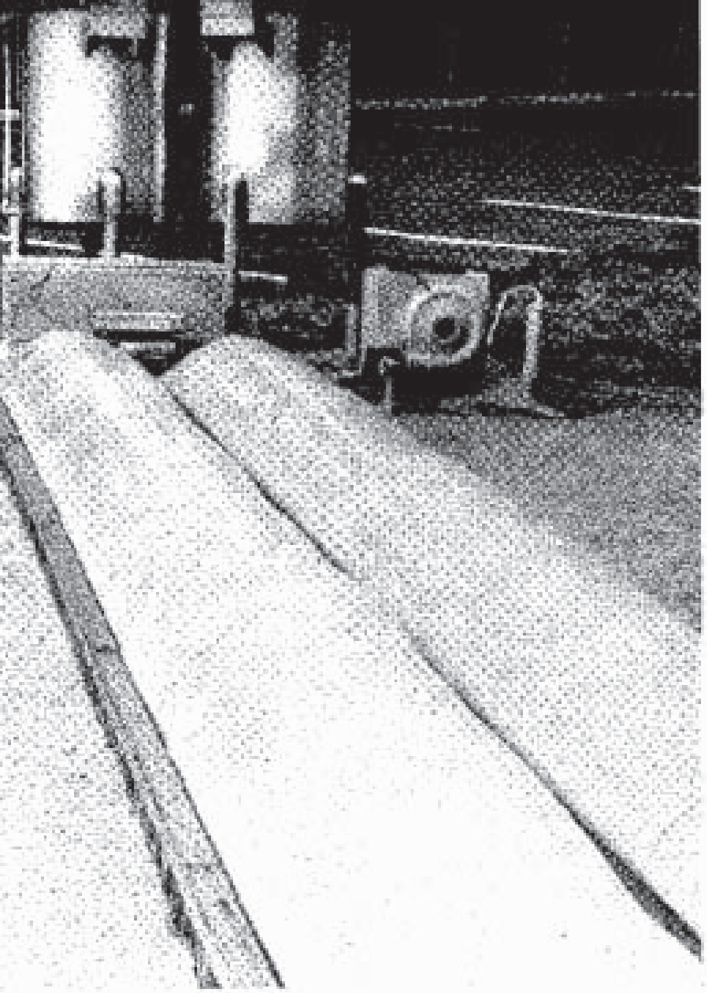
Centrale électrique Westinghouse à Koweït, sur le golfe Persique. On distingue cinq évaporateurs à trois éléments, déjà en service (capacité totale: 600 000 gallons US [1 gallon US = 3,78 litres] par jour) et trois des quatre évaporateurs à quatre étages du type «flash» (capacité de chacun: 630 000 gallons par jour), encore en construction. (Westinghouse Electric Corp.)



XII Bjorksten envelope solar still.

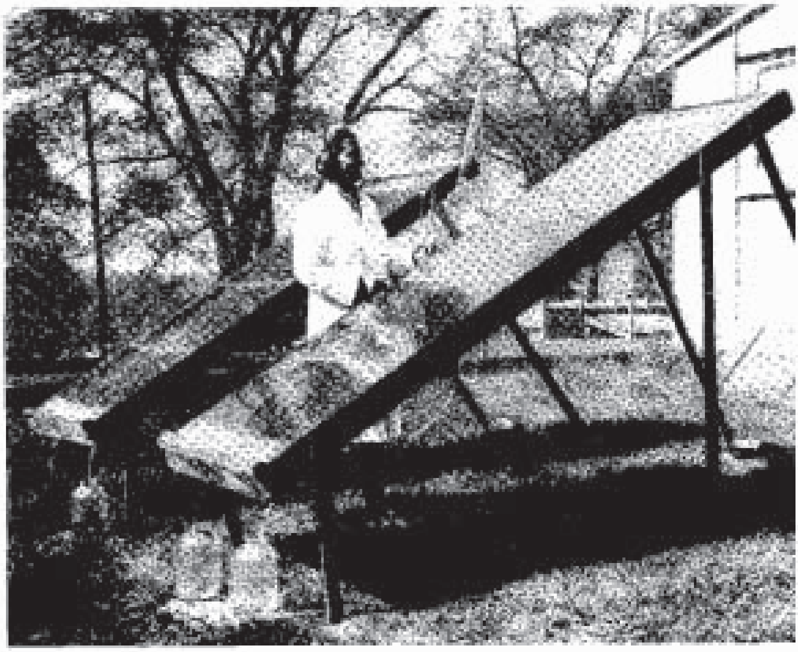
Distillateur solaire Bjorksten à enveloppe.

(*Article Jenkins, p. 307; photos submitted by the author / photos fournies par l'auteur.*)



xiii Dupont canopy solar still.

Distillateur solaire Dupont à couverture.

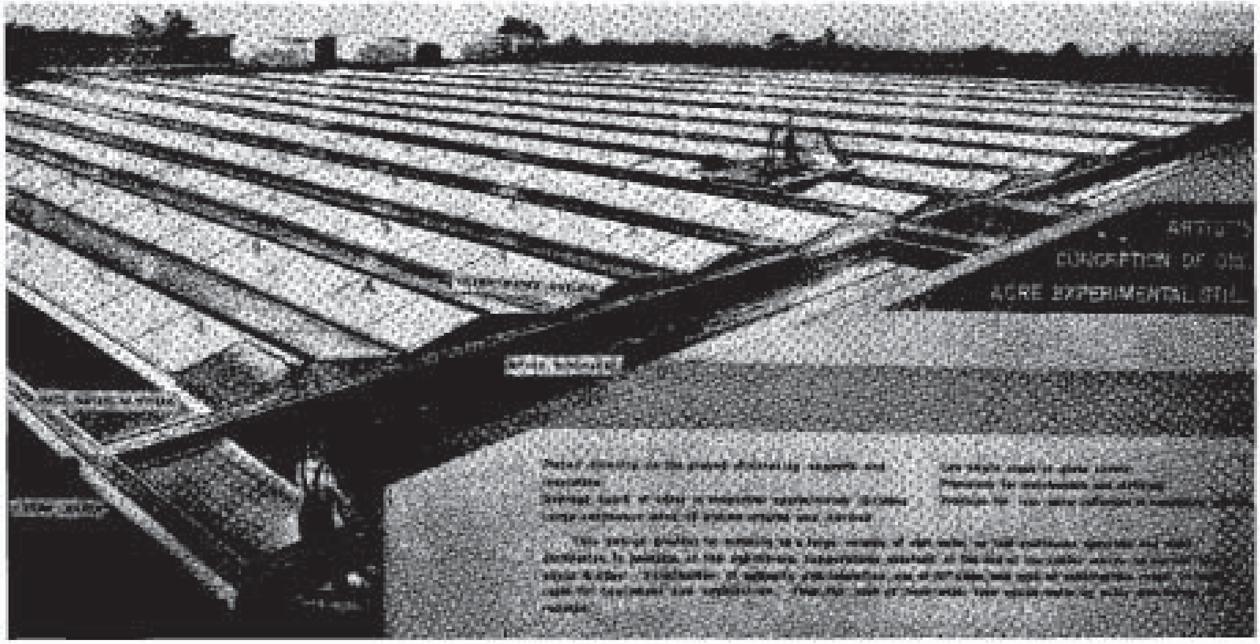


xiv Telkes' flat-tilted solar still.

Distillateur solaire de Telkes à plan incliné.

xv Löf deep-basin solar still. (Artist's conception.)

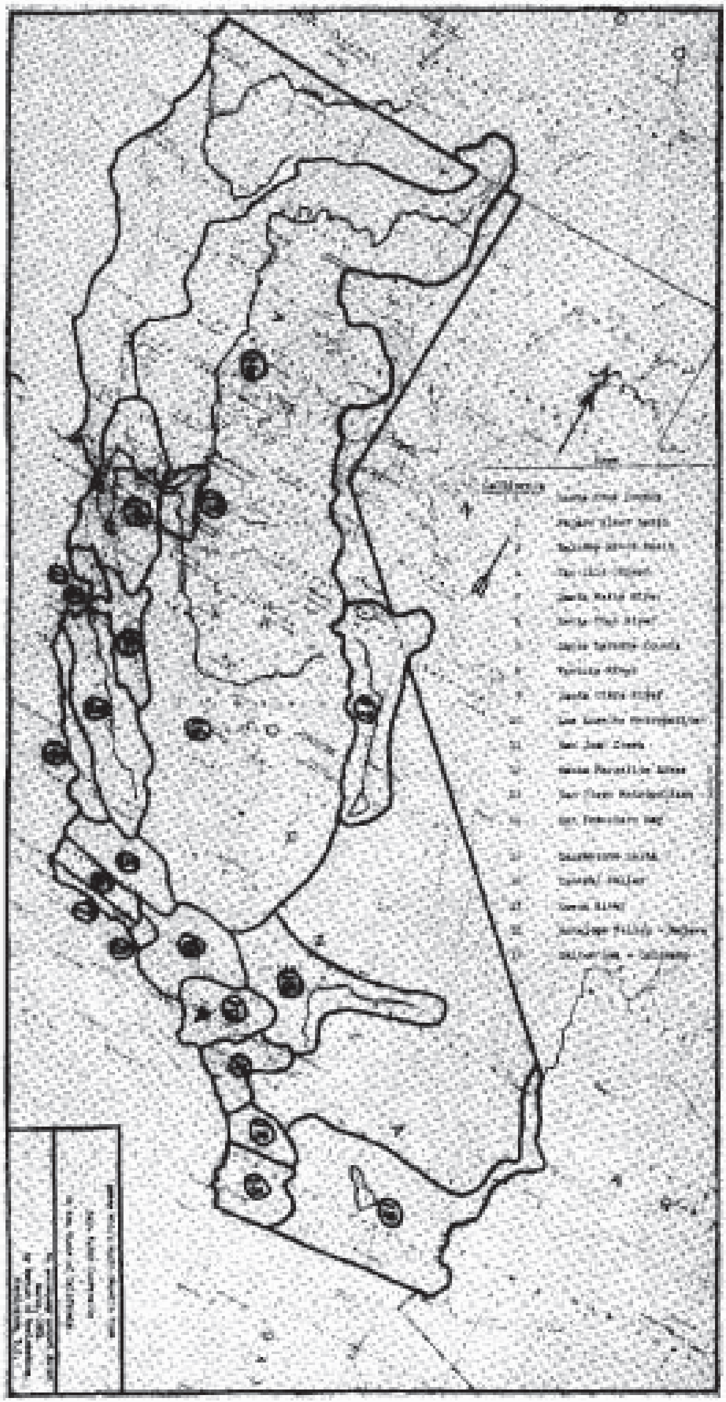
Distillateur solaire de Löf à réservoir profond. (Dessin.)



(Article Jenkins, p. 307; photos submitted by the author / photos fournies par l'auteur.)

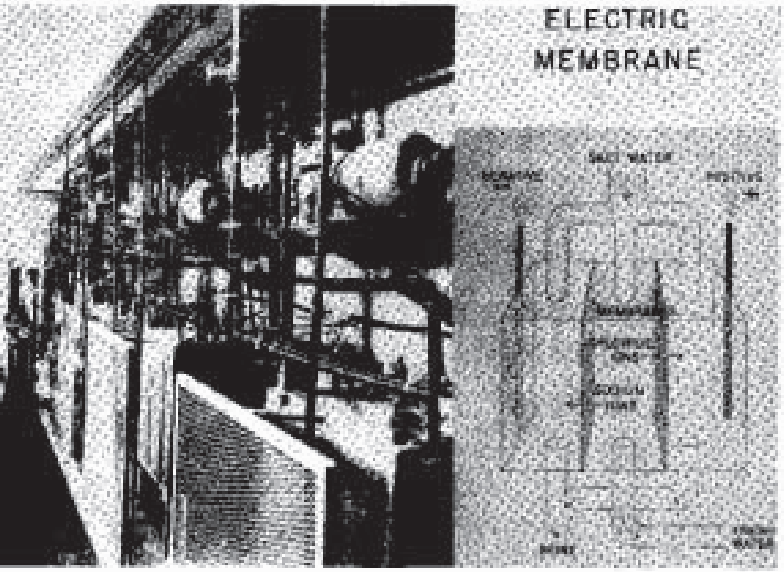
XVI Areas which might benefit from salt water conversion in the State of California.

Zones devant bénéficier de la conversion de l'eau salée dans l'État de Californie.



XVII Electric membrane process.

Procédé électrique (dialyse).



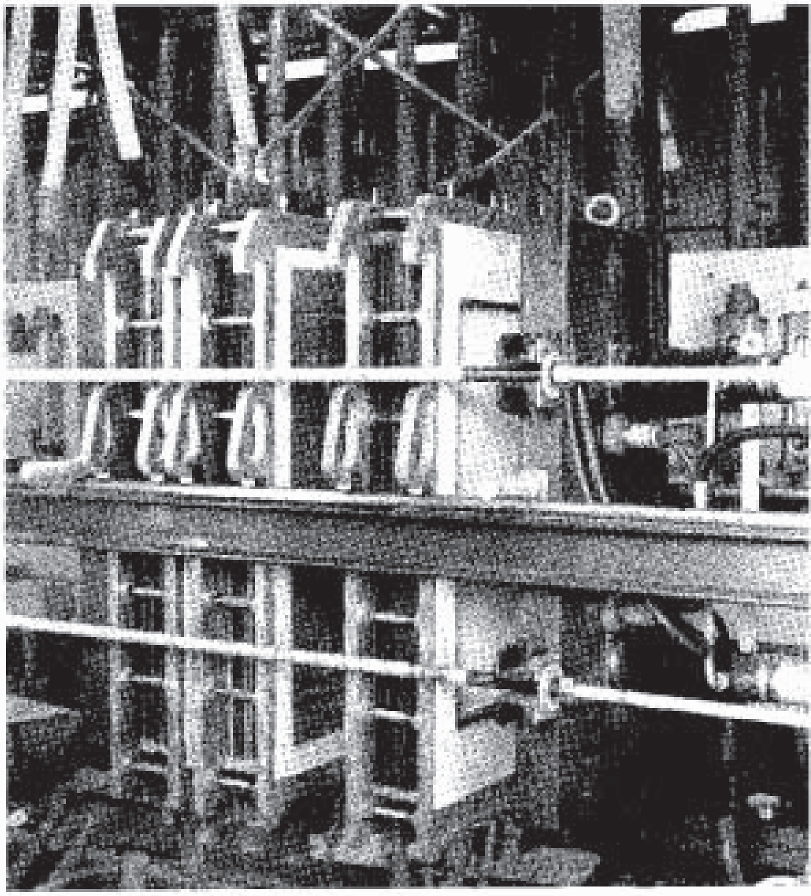
(Article Jenkins, p. 307; photos submitted by the author / photos fournies par l'auteur.)

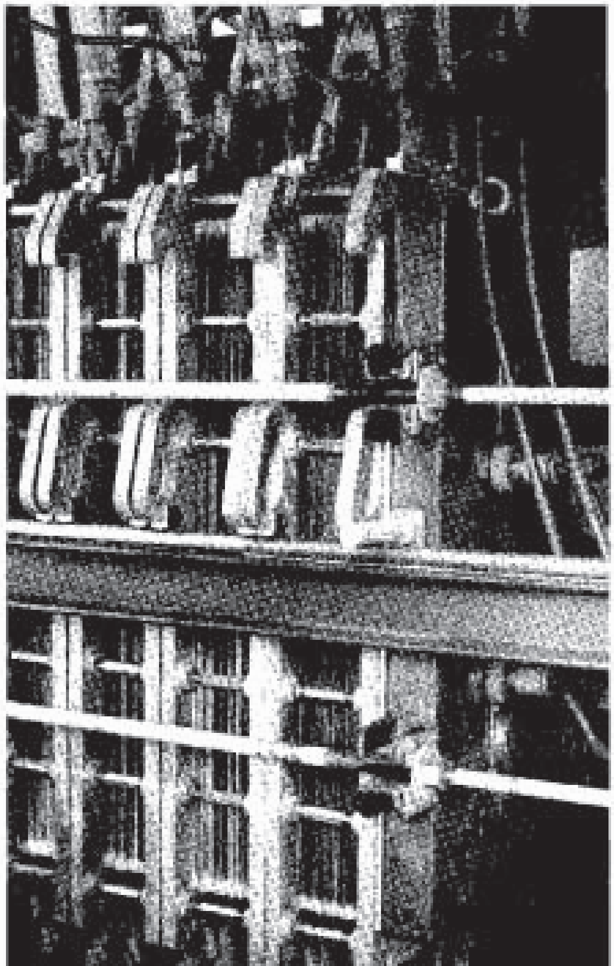
XVIII Separate subdivisional membrane stack, comprising 2 × 50 membranes.

Elément d'électrodialyseur constitué par 2 × 50 membranes.

XIX Exploded view of standard electrodialysing unit, showing subdivisional stacks and end plate with hydraulic pressure cylinders.

Intérieur d'un électrodialyseur de type standard. On voit les éléments et la plaque de bout avec les cylindres à pression hydraulique.

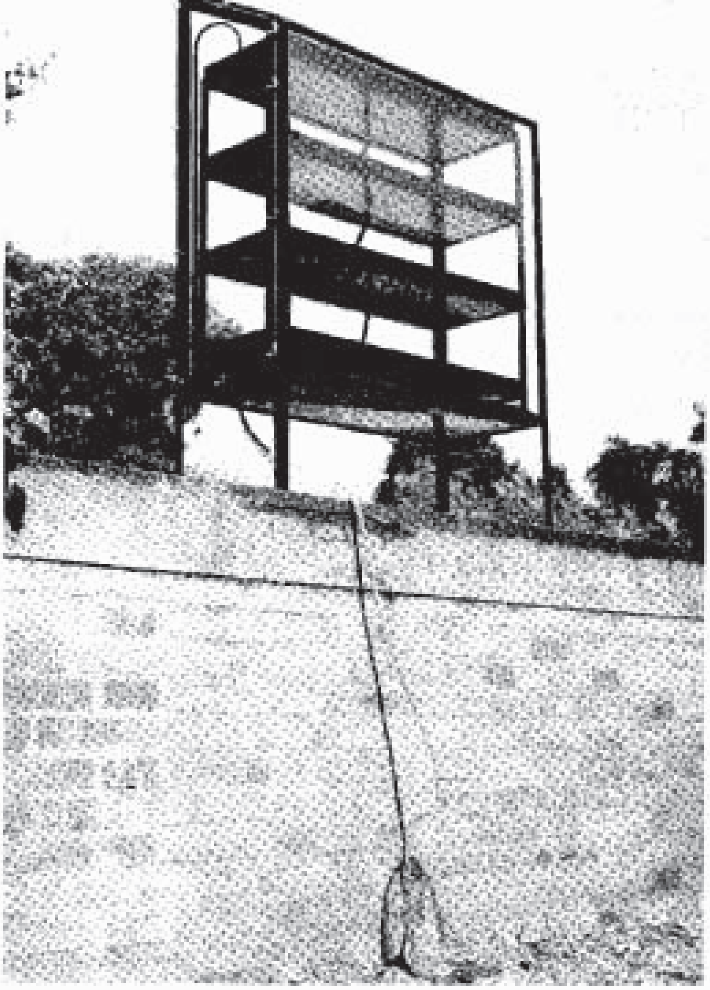




XX View of standard electrodialysing unit in operation.

Électrodialyseur de type standard en fonctionnement.

(Article Hamaker, p. 345; photos submitted by the author / photos fournies par l'auteur.)



XXI General view of the vertical solar still.

Vue générale du distillateur solaire vertical.

XXII Showing the overflow system for feeding the trays.

Démonstration du système d'alimentation de cuvettes par débordement.

(Article Nebbia, p. 393.) [*Photo G. Macchiavelli, Bologna.*]

IV

DEMINERALIZATION OF SALINE WATER

DÉMINÉRALISATION DES EAUX SALÉES

FRESH WATER FOR ARID LANDS

by

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U.S. Department of the Interior, Washington, D.C.

Before entering upon specific discussion of the arid-lands problem, I wish to review the course of the research work into saline water conversion that is being conducted under the Office of Saline Water [25][1], and elsewhere, and mention some processes that have been studied.

In order to separate water from a salt-water solution, we must expend energy [23]. The minimum theoretical thermodynamic energy needed to separate water molecules from salt ions can be calculated from the experiment shown in fig. 1. At the same temperature and pressure, more water molecules will change into the vapour phase from the fresh water (left) than from the salt water (centre). By compressing the vapour above the salt water to the same pressure as that above the fresh water, it can be made to condense to fresh water (right). The energy required is just equal to the energy that binds the water molecules to salt ions. For sea water this minimum requirement is 2.8 kWh per 1,000 U.S. gallons. Inventors' claims involving energy requirements less than this minimum are bound to be false.

The actual energy needed to evaporate fresh water from salt water is necessarily much greater than this theoretical figure, which assumes a barely perceptible rate of separation and complete efficiency in conversion of energy. Murphy [30] has estimated that this minimum energy requirement for a practical process may be about four times the theoretical, or about 12 kWh per 1,000 gallons. Simple distillation, for example, requires 1,000 times as much energy, but already distillation systems of today require energy expenditures of only about 200 kWh per 1,000 gallons.

Distillation, known and practised for long ages, remains to date the most advanced (and almost the only) method of applying this energy to the work of salt water separation. While simple in basic principle, it is complex and costly in application, and involves the use of large and expensive equipment. To discover other methods, the Office of Saline Water upon its establishment undertook an extensive survey [4] of scientific and technical knowledge. Included were various physical, chemical and electrical actions, as well as several modifications of the conventional distillation process designed to increase the productivity and reduce the size and cost of the necessary equipment.

Some 30 potential conversion processes and pertinent phenomena were originally listed as a result of this survey, but they were soon narrowed down to 16, which in turn were ultimately reduced to five groups of processes, namely (a) thermal and mechanical distillation; (b) solar distillation; (c) membrane processes; (d) freezing; and (e) others, including such processes and phenomena as ion-exchange, solvent extraction, and biological action, etc.

To date these studies [26], as well as parallel researches abroad, have shown that several processes other than distillation are technically feasible on the laboratory scale; only one has reached actual commercial use, however. This is the recently developed process of electrodialysis, in which the ions composing the salt are forced out of the saline water through pairs of positive and negative ion-selective membranes by the force of an electric current. One other process—separation of water from salt by freezing—is approaching the point of commercial possibility, but it still requires much further development. And, as part of the distillation group, small low-temperature stills using the heat of the sun have been extensively developed experimentally on a small scale basis in the United States and elsewhere, particularly in several Mediterranean countries and Australia.

DISTILLATION

Improvement of conventional distillation processes, both to reduce their high investment cost by increasing the rate of heat transfer and to reduce the energy cost by diminishing the heat losses, engaged extensive study from the first. The earliest projects of the Office of Saline Water included studies of very large vapour-compression

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[1] The figures in brackets refer to the bibliography on page 315.

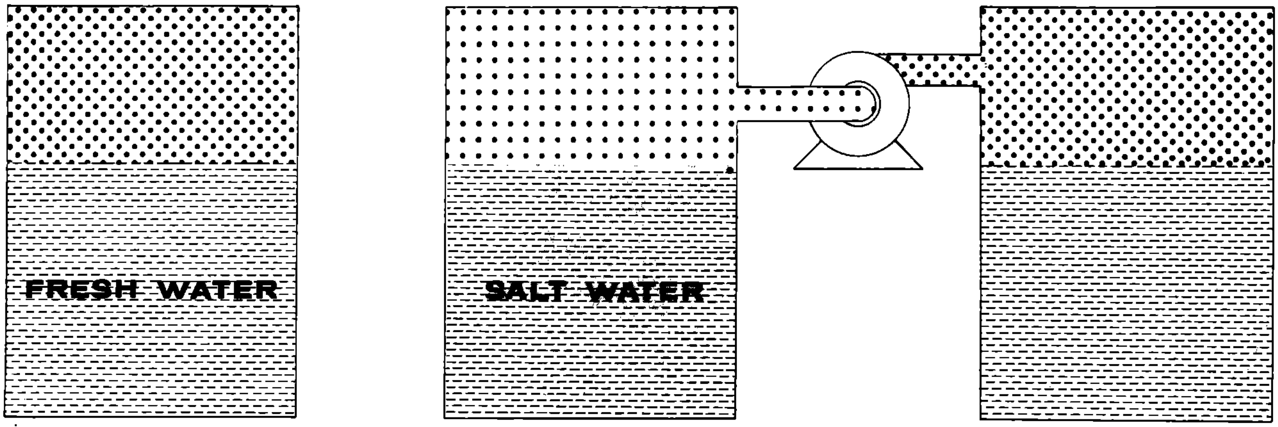

FIG. 1. Energy requirement for desalting illustrated by vapour pressure differences.

systems [9] and the possibility of reducing their costs, as well as large-scale multiple effect evaporation systems separately and in combination with power-generation cycles.

Although there are several different types of distillation equipment and cycles [5], all are at present subject to the same general limitations—scale deposition and corrosion. Scale-forming constituents, principally calcium carbonate, calcium sulphate and magnesium hydroxide, are precipitated out of solution as evaporator temperatures rise above about 160° F. The scale fouls heat transfer surfaces and impedes fluid circulation. In addition, brines become more corrosive, necessitating use of expensive alloys as temperatures approach or exceed the normal boiling point of water, 212° F.

Therefore, a series of research and development studies has been in progress in the fields of heat transfer, scale prevention, and less expensive corrosion-resistant construction materials. In most instances, each of the principal investigations—which are described below—is directed toward a particular evaporator type. However, much of the knowledge, and many of the techniques, gained from one series of experiments, where successful, will be adaptable to the general distillation field.

Formation of scale deposits in the equipment is a serious problem in practically all distillation processes, and under certain conditions in electrodialysis. A fundamental investigation of the basic factors affecting scale deposition is being conducted at the University of Michigan.

An attractive distillation process using long tube vertical evaporators of the kind employed in the salt industry has been proposed by W. L. Badger, Ann Arbor, Michigan [3]. In this cycle sea water is passed through a series of evaporators under reduced pressure and temperature, utilizing either heat applied directly from a steam generator or that recovered from the exhaust of a steam turbine in connexion with electric power generators [14] (fig. 2). The efficiency and economy of the process requires completely scale-free operation, which we believe can be achieved through *p*H control and/or internal sludge stabilization techniques. In addition, Badger proposed the use of low cost (ferrous) metals throughout the plant. In order to bring these theories into practice, a pilot plant was erected on a seashore site in North Carolina for testing scale prevention, metals corrosion, heat transfer rates, and other variables for the long tube vertical evaporator distillation process (Plate X). Badger estimates the total cost of water from a large plant at about U.S. $0.40 per 1,000 gallons.

Improved evaporators in which greatly increased rates of heat transfer are achieved give promise of reducing capital as well as operating costs. In one such development [32], the heat transfer coefficient is increased to 2,000–3,500 BTU/sq.ft./°F./hr., as compared to 500 or less in conventional equipment. In this process, invented by Dr. Kenneth C. D. Hickman of Rochester, New York, the heat transfer area is in the shape of conical surfaces and is rotated, thereby causing the feed water to spread over the surface in thin films, under centrifugal force. Several experimental models have been built, from household sizes (300 gallons per day) to much larger plants (25,000 gpd.) (fig. 3), and are being tested on brackish, as well as sea waters.

Another heat transfer system is under development by Drs. B. F. Dodge and A. M. Eshaya of Yale University, New Haven, Connecticut. Tests were run on laboratory equipment at the university [29] which demonstrated that heat transfer coefficients of 2,000 BTU/sq.ft./°F./hr. could be maintained in a system utilizing forced circulation and dropwise condensation in vapour-compression distillation processes.

The flash type of distillation process is now receiving increasing commercial application. In this process, warm salt water enters an evaporation chamber in which the pressure has been reduced below the boiling point of the salt water, thereby inducing a portion of liquid to vaporize (flash) into steam. As with most of the present types of commercial evaporation equipment, the flash units have been primarily developed for marine use. However, Westinghouse Corporation of Pittsburgh, Pennsylvania, completed one of the largest distillation plants in the world at Kuwait (Plate XI), making use of the multi-stage flash process. This installation consists of four four-stage flash evaporators with a total capacity of 2.5 million gpd. Other companies are also offering multi-stage flash evaporators and other land installations are now being considered for this type of equipment. The Office of Saline Water is developing improved multi-stage flash distillers for potential combinations with nuclear process [37] steam reactors as this type of evaporator will make use of very large amounts of steam in civilian-type applications.

There are also locations where waste heat is generally available or where ocean temperature differences are sufficient to induce *flash evaporation* [15]. Therefore, low temperature flash evaporation was recently studied by the Griscom-Russell Company [36] of Massillon, Ohio, for the Office of Saline Water, as adapted to a single-stage flash evaporator using the energy of a stream of warm waste water from a power station of an industrial plant, or from natural sources. Estimates showed that, given a temperature difference of 30° F. between the warm and the cold water, plants of 100,000 and 10,000,000 gallons output capacity would produce fresh water from sea water at over-all costs of $1.28 and $0.71 per 1,000 gallons respectively, using the Office of Saline Water Standardized Cost Estimating Procedure [24] as modified for this process.

SOLAR DISTILLATION

Distillation by means of solar heat has the advantage of eliminating the cost of the fuel energy otherwise required. However, the diffuse nature of solar energy makes necessary the use of large areas for collection. The major problem in solar distillation is reduction of equipment costs. Research on solar stills aimed at this and at increasing efficiencies has been carried out by the Office of Saline Water [21, 28]. Both glass and plastic membranes have found application as transparent covers for solar stills, and equipment costs are being reduced.

A number of typical American still designs, some intended for research use only, are shown in Plates XII, XIII and XIV. They include stills of suspended-envelope type, canopy type, and flat tilted type. Their output was found to be, rather uniformly, about 1 lb. fresh water per sq.ft. per average day of sunshine in a moderately warm climate.

A design for a deep-basin still with an area of 5,000 sq.ft. to be built directly on the ground was prepared in 1957 by George O. G. Löf of Denver, Colorado (Plate XV).

The Office of Saline Water has initiated a comprehensive development programme on solar stills through contract with the Battelle Memorial Institute of Columbus, Ohio. Prototypes of various existing and improved designs are being installed for further development at a central seashore test station near Port Orange, Florida. The first small pilot plant of the Löf deep-basin still is now being constructed there. The next two prototypes to be built will be of plastic films in place of the glass. The new plastic has been developed by the DuPont Company of Wilmington, Delaware. One will be based on the design shown in Plate XIII, using an air-supported transparent cover, and will also have an area of about 2,500 sq.ft. Low cost preformed concrete bases under development are expected to reduce costs further and greatly simplify field construction. The second DuPont type of about 500 sq.ft. was originally designed to utilize a wire support for the plastic cover. Recently, however,

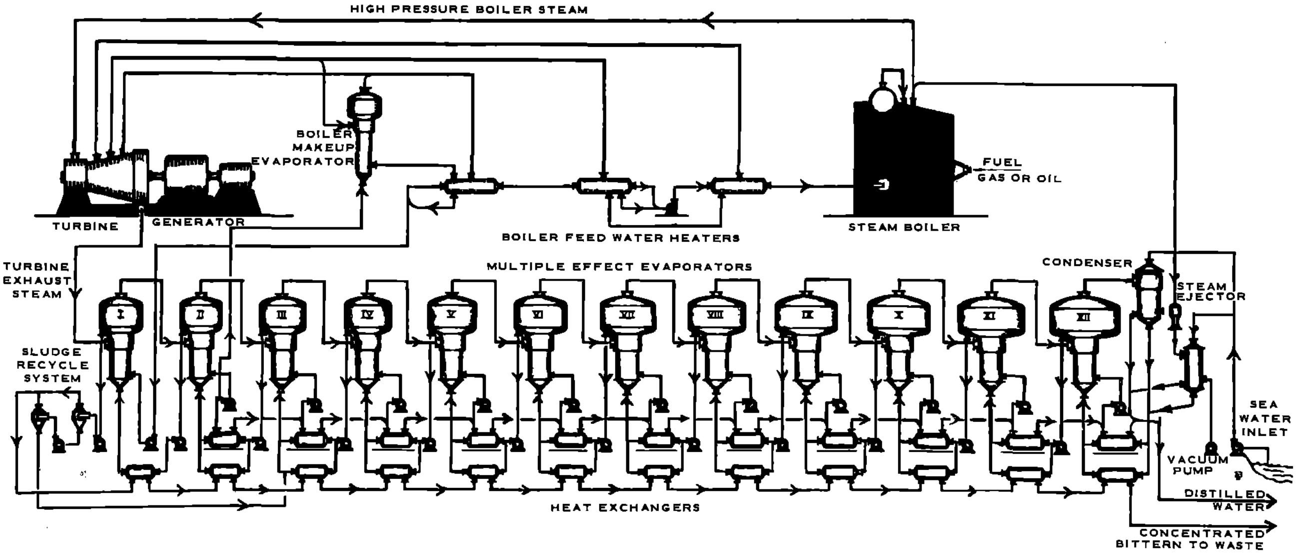

FIG. 2. Flow sheet of sea water distillation plant. (After W. L. Badger.)

DuPont has prepared a folded or pleated film which promises to remove the need for the wire support and further reduce costs. Others to be installed and tested at the Port Orange research centre are the suspended envelope developed by Bjorksten Laboratories of Madison, Wisconsin, and the tilted stills developed by Maria Telkes of New York University, both under the direction of the Office of Saline Water.

A need exists for two major types of solar distillation equipment: small stills, some of which may be portable; and large capacity stills. The small stills should have production capacities that range from about 20 gallons to several hundred gallons per day of fresh water. The large stills would cover many acres. They would be most useful where other conversion methods are more costly or impracticable and where solar intensities are high and land costs low. Both types have attractive possibilities for areas where the stills can be constructed with local materials and labour. Much development work is necessary to reduce the unit cost on a per square foot basis.

It is anticipated that the Solar Distillation Centre in Florida will result in engineering designs and specifications for practical small units and will point the way for future solar distillation plants of much larger capacity.

MEMBRANE PROCESSES

Desalinization processes utilizing membranes have been developed during the past few years to the point where several are known to be technically feasible and one appears to be economically feasible for the treatment of brackish waters under certain conditions [6].

Specifically, the membrane processes showing promise for the purification of brackish waters consist of: (a) electrodialysis, where an electromotive force is applied to a cell consisting of ion selective membranes; (b) "osmionic" process, where the concentration gradient between the solutions supplies the potential to drive ions through ion-selective membranes; and (c) reverse osmosis, where sufficient pressure is applied to the solution to force water through an ion-restraining membrane into the fresh water side. The practicality of using biological membranes through the use of algae is now being investigated by the Office of Saline Water [16].

One of the limiting factors in the use of these processes has been the membranes themselves. Consequently, during the past few years, considerable research has been conducted by organizations in several countries aimed at improving the characteristics of those membranes. As a result, greatly improved ion-selective membranes have been developed. Such membranes are now available commercially at a cost per unit area of approximately one-fifth of what it was formerly.

If the cost of membranes and equipment can be further reduced, some authorities believe that the use of ion-selective membranes for the demineralization of sea water might become economically feasible.

Electrodialysis

An electrodialysis cell consists of alternate cation and anion permeable membranes (Plate XVI). On the application of an electromotive force the positive ions, such as sodium, pass through the cation permeable membranes, whereas the negative ions, such as chloride, move in the opposite direction and pass through the anion permeable membranes. Thus the water passing between alternate membrane pairs is depleted of salt, while that passing through the intervening pairs is enriched.

Electrodialysis has developed rapidly as a conversion process from a laboratory phase to commercial operating units in about six years. Developments have been carried out in the Netherlands [41], Great Britain [12], South Africa [40], and the United States [20], and more recently in Japan, Soviet Russia [45], and Israel.

One of the most advanced processes is that of Ionics Inc., of Cambridge, Massachusetts, developed through assistance of the Office of Saline Water. That process utilizes strong membranes having considerable durability, and a long tortuous flow path. Following laboratory tests that had highly favourable results, the process was incorporated in pilot tests [31]. The equipment, which was mounted in a trailer truck, was operated for some months on two naturally occurring saline waters in Arizona and South Dakota with salinities of 4,000 ppm. and 2,000 ppm. respectively. Operating difficulties such as fouling by scale were corrected by acid feed, and the process was in each location successfully carried to a residual 350 ppm. concentration. The high cost of equipment and membranes at present quoted prices accounts for about 80 per cent of the cost of the water. With future increased production, these costs should be reduced.

The other well-advanced process is that of the Netherlands, TNO, also used in modified form in South Africa, in which thinner, less durable, but less expensive membranes are used in a continuous sheet-flow process. The one South African plant is reported to have a capacity of 2,400,000 imperial gallons per day.

Osmionic

The second membrane process mentioned is known as osmionic, a term which was coined because of the osmotic and ionic forces involved in the process [33]. This is one of the new processes developed under the Saline Water Conversion Programme of the United States and is somewhat similar to electrodialysis, except that it requires no outside electric current and no electrodes. The driving force is obtained from the difference in concentration between a brine and the water to be demineralized. The power supply might therefore be obtained from salt deposits, brine wells, or by ponding saline water and allowing the sun to concentrate the water.

In the simplest form of the apparatus, two cation and two anion selective membranes form a three compartment cell (fig. 3). Each chamber initially contains feed water, and the assembly or unit cell is immersed in brine. The passage of ions from brine to the less concentrated water in the outer chambers through the appropriate membranes is necessarily electrostatically coupled with the simultaneous transfer of ions from the centre to the outer chambers.

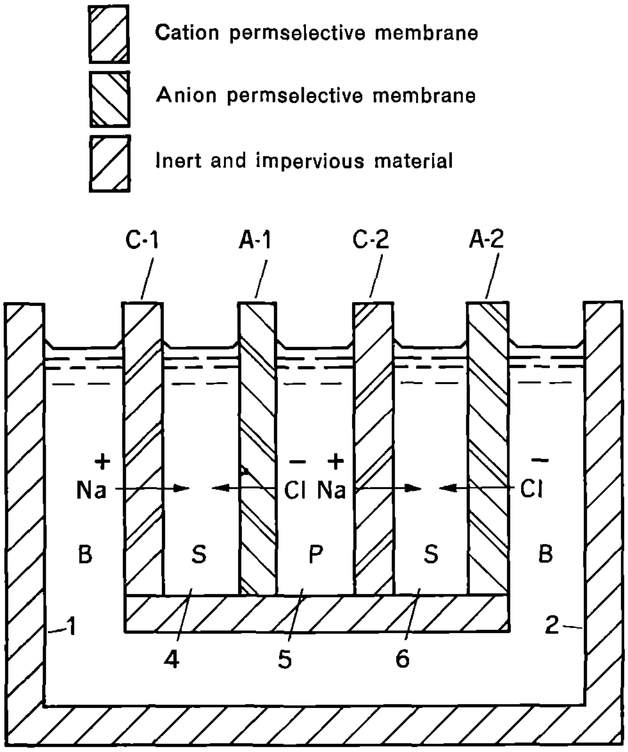

FIG. 3. Unit cell: osmionic process.

Reverse osmosis

Osmosis involves the passage of water through a membrane from a dilute solution to a more concentrated one [35]. If enough pressure is applied to the more concentrated solution (more than 350 psi. for sea water), then the osmotic flow can be reversed and pure water will be forced through the membrane. Results of research sponsored by the Office of Saline Water have demonstrated that around 97 per cent of the salts of sea water can be removed in one pass through a membrane, such as cellulose acetate, but at a slow rate. Investigation aimed at increasing the durability and flow rate of membranes is continuing.

FREEZING

Salt water separation by freezing has been the subject of a number of experimental researches [10, 19, 22, 39, 44]. The use of freezing has certain inherent advantages such as a lesser tendency toward scaling and corrosion because of the low temperatures involved and the lower value of the heat of fusion as compared to the heat of vaporization. There is also the advantage of low temperature differentials. However, the occlusion of brine with ice crystals has been a major difficulty in the development of a feasible process.

A promising approach to the utilization of freezing as a means of saline water conversion and elimination of the brine from the crystals is a combination of freezing with evaporation that is being investigated by the Carrier Corporation of Syracuse, New York. Experimental apparatus and washing techniques have been developed so that now it is possible to produce practically salt-free ice from sea water in a continuous manner.

Figure 4 illustrates a version of the process. Chilled saline water is admitted to a chamber under high vacuum. In this low pressure about one-seventh of the water flashes to vapour, further chilling the remainder which freezes to an ice-brine slurry. The slurry flows through a separation column for counter-current washing. The vapour formed in the freezing operation is compressed and condenses on the ice. The melted ice becomes the fresh water product. Part of the product is used for washing the ice.

The experimental programme on this process, utilizing a small shop-size pilot plant, has not disclosed any technical problems that could not be solved or that would render the process impracticable. Operation of the equipment is continuing and preliminary designs of a larger pilot plant of about 15,000 gallons daily capacity are being made. The next step is the construction of that pilot plant, incorporating all components of the complete process.

In another approach to the use of freezing for demineralizing saline water, an immiscible refrigerant such as isobutane is vaporized in direct contact with the saline solution. The development of this principle is under way at Cornell University [42], Ithaca, New York. Because most of the equipment necessary for this process could be of comparatively simple design, it may be particularly adaptable to large-scale installations.

Some rather basic research has been conducted in an attempt to adapt the zone-refining technique to convert saline water. A frozen zone is passed along a column of salt water to concentrate the salt impurities at one end. This has been done and fresh water actually obtained, but rates of production are very low; it remains to be determined if there is a basis for a practical method.

Research and development on demineralization by freezing appear worthy of great emphasis. The inherent advantages of this method indicate that a freezing process when completely developed should be able to compete economically with the most promising developments in the distillation field.

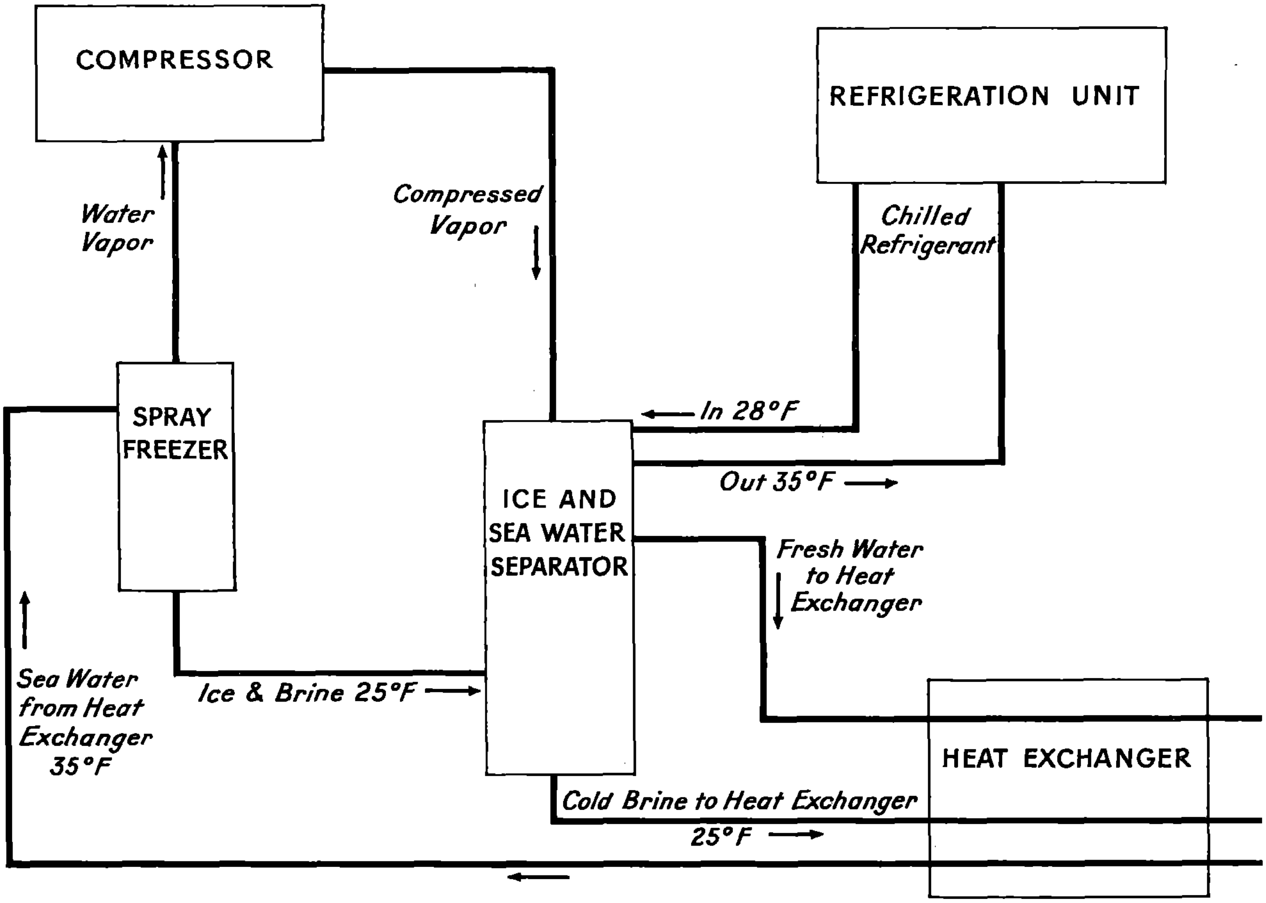

FIG. 4. Carrier Corporation freeze evaporation process.

OTHER PROCESSES

Ion exchange

Salt ions can be removed from saline water by passing the water through a mixed-bed of ion-exchange material. That material soon becomes saturated and must be regenerated by use of relatively expensive acids and bases.

To overcome this excessive cost, a process suggested by Gilliland [7] is being developed at the University of California [13], at Berkeley, which employs ammonium bicarbonate as a regenerant. When saline water is passed through such a bed, it is demineralized and the effluent consists of water containing only ammonium bicarbonate. Heating the solution removes the chemical as carbon dioxide and ammonia gases, which are collected and used again to regenerate the exchange resins in the bed. Thus, the costly chemicals used for regeneration are replaced by heat. Solar heat may be applicable.

More information, such as the type of construction materials required, durability or life of the exchange resins, etc., is essential before precise cost estimates can be made.

Solvent extraction

The extraction of water from saline solutions by an organic solvent, to be recovered later from the extracted mixture of water and solvent by temperature change, has been found sufficiently promising to justify further research. One of the best solvents [11] so far found is N-ethyl-n-butyl amine, which extracts about 30 per cent water at 30° C. and retains about 13 per cent at the separation temperature of 75° C. The process is under development at Texas A. & M. College and satisfactory laboratory equipment has now indicated the need for pilot plant development, which is being initiated.

Biological action

Preliminary study of the desalting action of biological membranes has very recently led to research under the United States programme in which algae are to be grown in a basin of sea water to take up salt and later removed to a second basin for partial removal of the salt taken up [16]. Pure cultures of several hundred algae have been grown in synthetic sea water and tests are starting on determination of salt uptake.

Use of nuclear energy

Owing to the high cost of nuclear-generated electrical energy, it was originally felt that nuclear energy would probably not play an early role in saline water conversion. However, in 1957, the Office of Saline Water undertook a study of the possible direct use of low temperature nuclear heat in evaporation processes. Following a preliminary investigation carried out by the Office of Saline Water [37], the U.S. Atomic Energy Commission and the Fluor Corporation of Whittier, California, a design study is now being made of two nuclear-heated plants employing improved flash distillation, one of 1 million gallons per day, the other of 20 million gallons per day.

Substantial non-federal research and development in desalting has been conducted in the United States by private industrial organizations. That work consists mainly of practical improvements in multiple effect, flash, and vapour compression distillation, and development of electrodialysis. The University of California [13] has carried out a research and development programme in several fields including distillation, solar distillation, ion exchange, and osmosis, and has undertaken several types of exploratory research.

COST TRENDS

Saline water conversion is complicated not only by process difficulties, but also by the range of water requirements encountered. Saline waters often vary widely in chemical composition, and the converted water is subject to various demands of quality. Sea water is fairly uniform in composition, with about 35,000 ppm. of salts. On the other hand brackish inland waters are quite variable in total salts and often call for special treatment to reduce or eliminate deleterious compounds, unsuitable for use by plants and animals, or for human consumption or industrial purposes. Hardness may be a further factor, and quantities will vary from small household demineralizers to large central plants. Thus, desalting is at times a custom process rather than a merely routine salt removal treatment.

In most instances the consumptive demand will be quite variable, and storage will be necessary to permit of uniform operation of the conversion plant. Raw-water storage may at times be necessary to take up fluctuations in supply. Depending on source and use conditions also, distribution from a central plant may be more efficient and economical than operation of several plants in the same general region. The drawing off and conveyance of desalted water from the seashore will constitute a major cost.

Such variations in the requirements with regard to practical application of saline water conversion will obviously affect design and cost planning. Process costs alone are therefore likely to be an inadequate guide to the total cost of converted water. When supply to a population of some size is at issue, moreover, reliability of services becomes a vital requirement and is likely to influence decisions on choice of process and planning of the conversion plant. In view of these and other considerations, the United States Congress recently authorized the construction of five demonstration plants, two of which will have a capacity of at least 1 million gallons per day. The five plants, to be built at both seashore and interior sites, will provide invaluable information on the cost and value of large-scale saline water conversion.

Compared to other developments such as atomic energy, the amount of research and the practical development effort devoted to saline water conversion has been very small indeed. Nevertheless, considerable commercial utilization has been made of the results, as shown on pages 92 and 104 of the Department of Interior's report on saline water conversion for 1957 [25].

In the matter of cost of conversion, detailed treatment is being given in the paper at this symposium by Professor Everett D. Howe of the University of California. In a briefer consideration of costs here, we would point out that early in the research programme it was found that few engineers or industrial firms used similar factors for computing costs. Some inventors and others omitted many of the factors when estimating costs.

As a practical matter, therefore, the Office of Saline Water concluded that a standard cost estimating procedure should be developed and that has been done. The method is sufficiently flexible to be usable in any locality, appropriate adjustment being made to the cost factors.

Table 1 contains estimates of cost per 1,000 gallons by various saline water conversion processes in the United States, without credits for sale of power or other by-products.

TABLE 1. Cost estimates

Process	1952 existing installations		1957 designed or projected installations		1960–70 anticipated (if further research is successful)	
	Sea water 35,000 ppm.	Brackish 5,000 ppm.	35,000 ppm.	5,000 ppm.	35,000 ppm.	5,000 ppm.
	$	$	$	$	$	$
					Less than	
Distillation (including solar)	2–5	2–5	1–3	1–3	0.50	0.50
Membrane processes	*	*	6	0.80	1.00	0.25
Freezing	*	*	*	*	0.50	0.50
Others	*	*	*	*	0.50	0.25

* Not developed.

It will be seen that distillation costs show some reduction as compared with those reported six years ago, and that further reductions are forecast for all processes, although their acceptability for large-scale irrigation of low value crops in the United States is not yet predictable. The price laid on the water could probably only be borne by high-value crops under most favourable circumstances of season and market, and for small homestead uses for vegetables and livestock. As processes are developed, costs reduced, and methods adapted to specific local materials and labour, the uses of converted sea and brackish waters are expected to increase.

APPLICATIONS TO ARID LANDS

So far as is known, the use of desalted water for irrigation is practised only to the extent of some subsistence and hydroponic farming. However, progress to date certainly justifies limited anticipation of some early agricultural uses without rigid equations of cash benefits to costs and some looking to the future when economic feasibility may be reached. For this purpose a preliminary study was made of irrigable areas in Texas and California [27]—at various elevations and distances from the coast—which need additional water and might be served directly or by exchange from converted sea water. This was done on a basin-by-basin basis as shown in Plate no. 8. For example, in basin no. 9 in California it was found that some 150,000 acre-feet of new converted sea water could be used on irrigable soils below 500 ft. elevation, after first making full use of all available fresh water supplies in the entire basin. In the lower Rio Grande basin in Texas some 1,650,000 acre-feet could be used on the same basis.

Similar information on areas bordering the eastern Mediterranean which might be reached with converted sea water could be compiled. Available topographic data indicates that there are more than twenty million acres of lands at elevations below 200 m. and within 100 miles of the sea coast in the eastern Mediterranean countries of Greece, Turkey, Syria, Lebanon, Israel and Egypt. Additional extensive areas of arable land undoubtedly border sources of brackish waters.

The foregoing has to do with irrigation only, but we should not be unmindful that more than three-fourths of the people in the world live at elevations less than 1,500 ft. above sea level. Thus, considerable ultimate municipal and industrial uses of converted saline water in these areas seem assured.

Finally, a word as to the future. It is believed possible that a considerable amount of further basic research to discover phenomena and processes not yet explored will prove justified. There are equal possibilities for much additional progress in the development and improvement of the specific processes discussed and partly explored to date in the quest for low-cost saline water conversion. These possibilities as well as those of basic research should be greatly furthered by improved co-ordination of the efforts of the various countries concerned, with a view to building on the foundation laid by the Washington symposium and continued by this symposium.

RÉSUMÉ

De l'eau douce pour les terres arides (D. S. Jenkins)

L'objectif d'un programme général de recherches sur les eaux salines est la mise au point de procédés permettant de fournir de l'eau douce en diverses quantités et au prix de revient auquel on peut consentir, en fonction des conditions locales, pour les différents usages de cette eau. Les variables du problème sont les suivantes: quantité, qualité et emplacement des sources salines; quantité, qualité, utilisation finale et prix de revient admissible de l'eau produite; enfin, les conditions locales, relatives aux matériaux, à l'énergie, aux ressources humaines, aux habitudes actuelles et futures touchant l'utilisation de l'eau, et la présence ou l'absence d'autres sources d'eau douce. Ainsi, de nombreux types différents d'installation de conversion seront nécessaires, depuis les petits alambics solaires produisant chaque jour quelques litres précieux d'eau potable jusqu'aux grandes installations d'une capacité de plusieurs millions de gallons[1], desservant de grandes villes où la consommation par habitant est élevée, et permettant éventuellement, dans certaines régions, d'irriguer des cultures déterminées.

L'auteur expose de façon très détaillée, avec illustrations à l'appui, les procédés sur lesquels on travaille actuellement aux Etats-Unis et dans d'autres pays. Il retrace brièvement les expériences qui ont été faites au sujet des vingt procédés différents d'abord proposés, en 1952, et décrit en détail les recherches et les travaux en cours au sujet des cinq techniques générales qui paraissent actuellement avoir le plus d'avenir, à savoir: la distillation, de trois types; la distillation solaire, de quatre types; l'utilisation, sous trois formes, d'appareils à membranes; la distillation par congélation, de deux types; enfin divers procédés chimiques, faisant appel notamment à l'extraction des sels par des solvants et à des échanges d'ions.

L'auteur ne parle que brièvement du coût de ces diverses méthodes, étant donné l'étude plus détaillée que présente sur ce sujet le professeur Howe. Néanmoins, pour les procédés les plus avancés et les plus prometteurs, il donne un tableau comparatif des dépenses d'équipement, d'énergie et d'exploitation, et il hasarde quelques pronostics quant au coût des méthodes de purification qui pourront être appliquées aux États-Unis mêmes.

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[1] Un gallon des États-Unis vaut 3,8 litres environ.

DISCUSSION

R. Ambroggi. (1) Quel est le prix de revient dans le cadre du projet de distillateur solaire du D^{r} Löf: *a*) du litre d'eau; *b*) de l'installation initiale?

(2) Y a-t-il d'autres projets aux États-Unis de grands distillateurs solaires?

D. S. Jenkins. (1) The cost of the water cannot be quoted as the installation is strictly experimental, with very heavy instrumentation.

The cost of installation of the experimental still is about $5 per sq.ft., but for a practical unit without experimental features cost is estimated at less than $1 per sq.ft.

(2) The University of California has a number of small experimental stills with a total area of about 1,200 sq.ft. No other larger pilot models are known to exist in United States beyond those being installed at Port Orange, Florida.

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DEMINERALIZATION OF WATER IN THE SOVIET UNION

by

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INTRODUCTION

The vast territories in the southern part of the Soviet Union, especially the republics in Central Asia and the Kazakh Soviet Socialist Republic, have an insufficient quantity of fresh water. At the same time these regions have, among their natural resources, large amounts of saline and brackish water which until recently have not been used for water supply because of their high concentration in mineral salts.

The Academy of Sciences of the U.S.S.R. directs the work being carried out in the country to solve the scientific and technical problems connected with the utilization of these waters to help supply the potable water requirements of the population and the industrial needs of arid regions. The problem of water demineralization is also being tackled by scientific research organizations connected with different branches of the national economy.

Work is being carried out on the theoretical study, the engineering development and the industrial application of various methods, the most promising of which are distillation, solar distillation, electrodialysis, freezing and ion-exchange.

DISTILLATION

Considerable work has been carried out by Soviet scientists and engineers on the study and working out of a theoretical basis for the choice of rational thermal schemes and the design of evaporating devices and installations. The theory of vapour-compressing units, which utilize the principle of the thermal pump and are less expensive than tube-and-shell evaporators, has been extensively analysed in relation to power consumption by Martinovsky [8],[1] Sergienko [14], Makinsky, Fedoseyev [3, 4], Sterman [15] and Tzygankov [18], while others have worked out some new designs and methods of calculation for distillation apparatus.

For large-scale use, single-stage distilling purifiers have been evolved (Yermolin design) [22] with an output of 2.7 and 30 t./day of fresh water from sea water. The following technical data apply to the 30 t./day installations: primary steam pressure, 0.5–1.0 kg./sq.cm.; secondary steam pressure, 0.03–0.05 kg./sq.cm.; distillate salinity, 15 ppm. Cl^-; consumption of heating steam per litre of distillate, 1.3 kg.; heating surface of coil tubes, 11 sq.m.; over-all dimensions 1,600 × 1,600 × 2,400 mm.; weight, 1.6 t.; term of operation between cleanings, 20–25 days.

In addition the following units are being manufactured [4]: (a) double-effect evaporators for 2.3–3.3 $m.^3$/hr.; (b) single-effect evaporators for 3.5–3.75 $m.^3$/hr.; (c) distilling units for 10 $m.^3$/day and for 3 $m.^3$/day.

Small-size distilling steam-compressor units, type "ED" [16] are also used. Output is up to 50 l./hr. of fresh water with a solid residue of 5–6 ppm. when dealing with sea water. The plant works with continuous purging of brine, the concentration of which is three times as high as the concentration of salts in the initial sea water. The service life of the installation between cleanings, when working with sea water, is about one month. Cleaning is performed by boiling the parts in a 5 per cent solution of hydrochloric acid.

The cost of fuel for demineralization by distillation is usually about 70 per cent of the total cost of water distillation. For the tube-and-shell type purifiers, high saving of fuel is obtained by increasing the number of stages to approximately three, which is considered to be the most efficient number.

Further increase in the number of stages of the installations calls for higher capital investments and operating costs, which are not compensated by the savings resulting from somewhat lower fuel consumption.

In 1938, Fedoseyev [3, 4] proposed a new method of surfaceless (instantaneous) evaporation which excluded the possibility of scale formation on the heat transfer surface.

[1] The figures in brackets refer to the bibliography on page 321.

TABLE 1. Fuel consumption for distillers of various types

Type	Consumption of liquid fuel (petroleum residue) in kg./m.^{3} of distilled water
Distillers without secondary steam compression	
One-stage	85–100
Two-stage	42–50
Three-stage	20–34
Four-stage	27
Single-stage steam-compressor diesel-power distillers	
Special small-size units with output of 15–25 m.^{3}/day	5.3–8
Same with output of 60–100 m.^{3}/day (with electric drive)	8–10

The layout and principle of operation of the Fedoseyev installation are as follows. Liquid fuel and salt water are sprayed into the combustion chamber by special injectors. The heat developed is directly consumed in water evaporation. The entire steam-gas mixture, together with the suspended matter caused by combustion and entrained matter in the water, is delivered to the electrostatic filter, where all entrained matter in the saline steam, soot and other products caused by fuel combustion, settle. After passing through the filter, the cleaned steam-gas mixture flows into a condenser, where it is transformed into a distillate. This method permits the purification of water having a high percentage of minerals: water with an initial salt content of 25,600 ppm. is distilled, yielding a residue containing 38 ppm.; an initial content of 250,000–300,000 ppm. yields a residue with 200 + 400 ppm.

Polozhy [10] has investigated the phenomenon of boiling in a jet with an atomization limiter. The use of this principle offers many possibilities for the creation of compact evaporators developing cheap steam of high quality.

SOLAR DISTILLATION

Solar distiller installations are likely to be widely used in the future for large territories in the Soviet Union, primarily in the Union Republics of central Asia, where the number of cloudless days per year reaches 200 to 300.

Research in the fields of solar distillation and heliology has been given much attention in our country. This has found its expression in the creation of special laboratories within the system of the Academy of Sciences of the U.S.S.R. and of the Uzbek S.S.R. It is planned to create a Solar Institute.

The basic work in this field is the investigation by V. P. Wineberg and V. V. Wineberg [20]. These workers have evolved a theory for the design of solar distillers, evaluating the heliological properties of distillers and giving indications for choosing the best type of unit. They consider it best to use devices for the concentration of the sun's rays, the devices having cheap mirrors of chrome-plated metal or of stainless steel. Fixed distillers are, as a whole, more economic: devices which follow the motion of the sun are expensive and complex, providing only a slight increase in efficiency and involving a considerable rise in the cost of the structure.

Trofimov [17] has designed solar distillers of a simple kind (inclined box type with internal condensation) which yield, at the latitude of Tashkent, approximately 6 l./day of pure water from one square metre of working surface.

Baibutayev [1] has carried out work on comparative testing of various systems of solar water-heating devices. A flat closed tubular installation proved the most efficient one. Devices of similar action have been designed and tested by Petukhov [9], with an output of up to 65 l./sq.m./day of water heated to 55° C. Tilted-box type distillers and water heaters are best placed on sloping roofs, facing southwards.

A method has also been proposed using a combined thermal-vacuum distiller with a solar water-heater [23].

According to data furnished by the Heliological Laboratory of the Academy of Sciences of the U.S.S.R. [13], the output of solar distillers of the fixed type, using regenerator schemes, may reach 12 l./sq.m./day.

A general report on the possibilities of using solar radiation for engineering purposes, and on the problems that arise, has recently been prepared by Baum [2].

ELECTRODIALYSIS

This method is considered to offer the best prospects for the demineralization of brackish water. The possibility of obtaining fresh water from the sea by this method was also investigated, as well as the elimination of salt in order to meet the needs of power engineering and technology for high purity water [7].

A pilot plant has been used to study several factors relating to the technology of the process, including current efficiency, flushing of brine chambers, specific power consumption, etc.

The practical values of current efficiency, when demineralizing water of the Black Sea from a salinity of 18 gm./l. to one of 0.5 gm./l., reached 80 per cent.

When treating river water with a solids content of approximately 400 ppm. down to 20 ppm., the current efficiency did not exceed 65 per cent. This phenomenon may be caused by lower selective permeability of the permselective membranes in the presence of the divalent calcium and magnesium cations and the sulphate and carbonate anions in the river water, while for chlorine and sodium ions in sea water the membranes are penetrated more readily.

Tests carried out in the pilot plant have shown the inadvisability of using sea water for flushing brine chambers at high degrees of desalting. The smallest value of specific power consumption corresponds to a ratio of average concentration of concentrating to dilute streams of 4 to 1.

The specific power consumption for demineralization at the present distance between the membranes and a given working cross-section of the cell is related to the degree of demineralization. As the initial salt content rises the given degree of demineralization is achieved by using more and more power. It was thus concluded that it is necessary to divide the installation into several successive demineralization stages, the number of which should increase with the initial salt content. The degree of demineralization must increase from the initial to the final stage of the process. The number of stages required is determined on the basis of the values of initial and final salinity, corresponding to the optimal degree of demineralization for each stage. Thus, for a high degree of demineralization of Black Sea water, 6 or 7 stages are required, with the degree of demineralization increasing from 33 per cent in the initial stage to 90 per cent in the final stage.

The necessity has been confirmed of ensuring intensive circulation of solutions in the cell chambers. When there is no circulation the value of the counter-electromotive force reaches 20 per cent of the value of the total voltage in the cell.

Water heating for high currents of up to 150 amps./sq.m. does not exceed 3–5°C.

Of great importance is the preliminary treatment of water, including clarification, stabilization and iron removal. When this is not performed lime, carbonate and ferrous deposits accumulate on the membranes.

At present, intensive work is being carried out with a view to obtaining highly satisfactory permselective membranes, as well as suitable apparatus for electrodialysis.

Several scientific research institutions are taking part in the development of permselective membranes. These are synthesized and of the heterogeneous type only, both for ordinary and high strength ones, for which a reinforcing net is applied. The problem of attaining high strength membranes is considered to be the most difficult and urgent one.

As regards the electrochemical characteristics, it should be noted that the results achieved can be considered as satisfactory. In particular, membranes have been received with a resistance of 15 to 20 ohm./sq.cm. at transfer numbers of about 0.9 for a 0.1 per cent solution of NaCl. Ion-exchange resins manufactured by the Soviet chemical industry are employed for making membranes: anion-exchange resin EDE–10 and cation-exchange resin SDV–3. Both of these resins have been approved for use in potable water mains by the State sanitary inspection authorities.

Electrodialytic installations are being designed with cells of the filter-press type—the number of chambers reaching 150—and with parallel distribution of streams of demineralized and salt water. Stainless steel is used as the cathode, magnetite being used as the anode. Preliminary treatment of the water is effected with a slightly soluble stabilizing agent specially synthesized to prevent clogging of brine chambers by calcium salts.

Specific power consumption may reach 15–20 kWh./cu.m. when desalting sea water, and up to several kWh./cu.m. when desalting brackish water.

When a high degree of demineralization is desired, it is best to remove the main quantity of salt by electrodialysis, and then to demineralize with ion-exchange filters.

FREEZING

Some scientific research organizations of the Academy of Sciences of the U.S.S.R. are engaged in the investigation of problems connected with the formation of ice from salty water and its thawing.

The development of practical methods for desalting water by freezing has been undertaken by Gueller [5], and also by Kliachko, Puchko, Zaitzev and others [19, 23].

The method proposed by Professor Gueller applies to the southern regions of central Asia, and makes use of the freezing night temperature and the positive day temperature. This method may also be used when the air temperature for at least 6 hours per day is at a level of —3° to —4°C.

The platform where freezing is performed is built on the communicating-vessel principle, i.e. by sections arranged in cascades. During the first night at freezing temperature, salt water is poured into the upper section, 20 cm. high. After thawing, the salt water under the layer of ice flows into the lower section, while the ice drops onto the corrugated bottom of the platform where it begins to melt. The first part of this water with an excessive salt content is drained off into the assembly tank, while the remaining, demineralized, part is guided into a collector.

It is thus possible to reduce the salinity of water from 15 to 0.47 gm./l., losing only one-third of the initial amount of water in salt-water drainage.

The method proposed by Professor Kliachko is intended for regions with lengthy winters. The conversion installation consists of a row of platforms for freezing, filled with the initial salt water. As it freezes, the ice is broken off and is conveyed to special storage or into premises for thawing.

The method worked out by Puchko is based on the freezing of salt water by layers into blocks of large dimensions, each of them up to 2.5 m. in height. Freezing occurs in thin layers. The water freezes rapidly without being demineralized during the freezing process, the salinity of the ice not differing from the salinity of the initial water. Water desalting is achieved only during the slow thawing in the warm season of the year. Using this method it is possible to reduce the salinity of water with an initial salt content of 9.3 gm./l. down to 1.1 gm./l., with losses for the discharge of salt water of up to 30 per cent of the initial amount of water.

ION-EXCHANGE

Ion-exchange demineralization is being used to a greater and greater extent for preparing water at electric power stations and in the chemical industry, where water with insignificant salt content is urgently required.

In this field fundamental investigations have recently been carried out in the Soviet Union; they have covered both the theory and the technical use of ion-exchange. Among these studies mention should be made of those by Yankovsky and Prokhorov [11], who have greatly contributed to our knowledge of ion-exchange resins as a special class of solid electrolytes, that of Smirnov [11], who investigated the dynamics of cation exchange, and that of Lapotyshkina [11] on the dynamics of absorption of anions.

A scientific method for designing ion-exchange filters has been developed by Kliachko [11].

Shkrob and Sokolov [11] have worked out theoretically basic recommendations and optimal methods for preparing water under various operating conditions for both high and super-high pressure boilers from initial waters of varying chemical composition.

Practical directions for the design of installations for ion-exchange demineralization have been prepared by Kastalsky [6].

The wide application of ion-exchange resins for the demineralization of saline water is not considered feasible by Soviet specialists.

An initial salt content of about 3–4 gm./l. is supposed to be the level suitable for the application of this method. Calculations made in connexion with the construction of an ion-exchange demineralization plant on the Aral Sea have shown that with a salinity of 5–8 gm./l. in the initial water, it is necessary, owing to the water requirements of the plant itself, to increase the rated output of the installation by almost 80 per cent. The water in the Caspian Sea has a salinity of 13 gm./l.; the useful output of fresh water is consequently 30–40 per cent of the total output of the installation.

However, Wolph, Moiseyev, Korystin and Novik [12, 21] have developed and recommended the use of mobile ion-exchange demineralization installations with changeable beds for temporary and prospecting water supply, making use of a low consumption of fresh water. The output of these installations, when the salt content of the initial water is 3 gm./l., reaches 90 l./hr.; with an initial salt content of 5–6 gm./l. the solids content of the water is about 1 gm./l. The ion-exchange resins used are regenerated at a special central service station.

The authors mentioned have also developed an ion-exchange demineralization installation of the stationary type, with regeneration of H and OH ion-exchange filters at the site [12]. This installation has an output of 5 cu.m. of fresh water per shift from brackish water, with a solids content of up to 5 gm./l. The consumption of reactants for each gramme-equivalent of salts removed is 1.45 gramme-equivalent of hydrochloric acid for the regeneration of the cation-exchange resin and 1.65 gramme-equivalent of soda ash for the regeneration of the anion exchange resin.

RÉSUMÉ

La déminéralisation de l'eau en Union soviétique

(O. S. Lenchevsky)

Dans les régions méridionales de l'Union soviétique, d'immenses territoires, qui ne disposent pas de quantités suffisantes d'eau douce possèdent d'importantes réserves d'eau saline ou saumâtre; aussi de nombreuses recherches sont-elles consacrées à l'étude théorique, à la mise au point technique et aux applications industrielles de diverses méthodes de déminéralisation de l'eau salée.

La théorie de la distillation par thermocompression a été étudiée de façon approfondie du point de vue de la consommation d'énergie, et l'on a établi de nouveaux projets d'appareils et de nouvelles méthodes de calcul dans ce domaine. En vue d'une utilisation en grand, on a construit des épurateurs d'eau de mer à un seul stade, qui fournissent trente tonnes d'eau douce par jour; plusieurs autres genres d'appareils plus petits sont également fabriqués. Le coût du combustible nécessaire pour déminéraliser l'eau par distillation atteint en général environ 70 % des frais totaux. Dans le cas d'épurateurs du type "contre-courant", on réalise d'importantes économies de combustible en portant le nombre des stades à trois; ce procédé est considéré comme le plus efficace.

Il est probable que la distillation par l'énergie solaire sera largement employée à l'avenir en Union soviétique, surtout dans les républiques soviétiques de l'Asie centrale. Un laboratoire spécialisé dans les recherches de ce genre a été créé, et l'établissement d'un institut solaire est prévu. Des recherches de base ont déjà été effectuées sur les caractéristiques des alambics solaires; les alambics fixes, dotés de miroirs peu coûteux en métal chromé ou en acier inoxydable, paraissent plus économiques que les alambics tournants. Divers systèmes de chauffage de l'eau par l'énergie solaire ont été expérimentés.

L'électrodialyse est considérée comme la meilleure méthode de déminéralisation de l'eau saumâtre; une installation pilote a été utilisée pour étudier les caractéristiques technologiques de ce procédé: efficacité du courant électrique, chasse des chambres à saumure, consommation spécifique d'énergie, etc. Il est indispensable de soumettre l'eau à un traitement préliminaire pour la clarifier, la stabiliser et éliminer le fer qu'elle contient. La mise au point de membranes "perm-selectives" du type hétérogène fait l'objet de nombreux travaux.

Des recherches ont en outre été entreprises sur la distillation par congélation et fusion. Dans les parties méridionales de l'Asie centrale, des expériences ont été faites en utilisant l'écart entre les températures nocturnes (inférieures à zéro) et diurnes (supérieures à zéro). Dans les zones où l'hiver est très long, le dessalage de l'eau est assuré seulement pendant le lent dégel qui se produit au cours de la saison chaude.

Enfin, l'emploi des procédés de déminéralisation par échange d'ions est de plus en plus fréquent dans les centrales électriques et dans l'industrie chimique; des recherches fondamentales ont été effectuées tant sur la théorie que sur la mise en œuvre de ces procédés.

DISCUSSION

J. Hamaker. Why was the energy consumption for the desalting of sea water increased from 15–20 kWh./m.^{3} to 30–70 kWh./m.^{3}?

O. S. Lenchevsky. This was due to the consequent increase of current density, correspondingly from 40–50 to 80–100 amps./m.^{2} (relating to brutto cross section of cell). This was done for the sake of intensification of process.

W. Boby. (1) What cell spacings are being used in the pilot plant?

(2) Are any homogeneous membranes being developed in U.S.S.R.?

(3) Has the use of sequestering agents been found economic?

O. S. Lenchevsky. (1) From 8 mm. (at the first stage of experimenting) to 3 mm. now, with a possible further reduction.

(2) Only on the laboratory scale.

(3) In my opinion this is a matter of urgent necessity rather than of economy.

B. A. Cooke. In South Africa we have made rough estimates of the cost of using well-known sequestering agents (such as ethylene-diamone, tetra-acetic acid) and have abandoned the idea on grounds of cost. What substance do you use and can you give an idea of the cost added to the process in this way?

O. S. Lenchevsky. We do use a special patented compound. The additional cost introduced thereby is quite a moderate one.

C. Gomella. A-t-on fait des essais systématiques de dessalement par électrodialyse avec des eaux autres que l'eau de mer? Dans l'affirmative, quelle est la composition chimique de ces eaux? Quelles ont été les difficultés rencontrées?

O. S. Lenchevsky. Oui, aussi avec les eaux saumâtres, telles que celles qui ont une salinité générale de l'ordre de 2–15 g./l.

Les difficultés principales sont: *a*) l'abaissement de la consommation de l'énergie; *b*) la prévention des dépôts de sels dans les chambres pour concentration des sels.

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UNITED KINGDOM DEVELOPMENTS IN THE DEMINERALIZATION OF SALT AND BRACKISH WATERS

by

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The three established demineralization processes are ion exchange, electrodialysis with ion-exchange membranes, and distillation. The United Kingdom is active in all these fields. However, ion exchange will not be dealt with in this paper since it is a well understood process and has been in full commercial application for many years; it should be noted in passing, however, that though straightforward ion exchange is not normally economically applicable to waters much above 1,000 ppm., tds., it is none the less in successful use in certain arid zones—e.g. Algeria—on waters of considerably higher concentration than this. This demonstrates that the choice of processes must always be a logistic exercise in which full regard must be paid to local conditions so that, for example, the cost (including transport cost) of regeneration chemicals for ion exchange is balanced against the requirements for power supply for electrodialysis and fuel oil or steam for distillation. It goes without saying that the differing requirements of these processes for maintenance and manpower, as well as their different levels of capital expenditure must also be evaluated carefully in terms of local conditions. Failure to do this has vitiated many cost estimates in the past and it has often been made insufficiently clear that generalized cost estimates are of limited value and can only be applied with the greatest care, if at all, to any particular locality.

ELECTRODIALYSIS WITH ION-EXCHANGE MEMBRANES

Since this technique is the subject of a separate paper in the present symposium it will not be dealt with in detail here. It should be recorded, however, that there is every hope that electrodialysis will establish itself commercially as the most economic process for waters containing less salt than sea water. Running costs rise as the salt concentration rises, but recent indications are that costs, even for sea water, may be less than was at one time anticipated. A number of different lines of research and development have been pursued in the United Kingdom in this field. The largest unit in the world to be based on this design is that now being constructed in South Africa for an output of approximately 3 million gallons per day.

However, the world's first commercial unit of this kind was produced by Wm. Boby Ltd., in the United Kingdom [9].[1] This unit underwent extensive trials on both synthetic and natural brackish water in the United Kingdom, before being sent out at the end of last year for installation in Libya. A batch process has been used in this plant, the raw water being fed to two tanks, from one of which it is circulated through the membrane stack until the desired degree of demineralization has been obtained. The second tank is then used while the first is emptied and refilled. Perhaps the main advantage of batch operation is that its power requirements are lower than those of continuous operation, but it also lends itself to automatic control; for example, the salinity of the stream being demineralized may be measured continuously by a conductivity cell and the changeover from one storage tank to another made automatically. In the membrane stack, the water is divided into two streams, one of which becomes more concentrated as the other is demineralized. Both concentration and demineralization will, in the batch method of operation, progress steadily as the operation proceeds; however, it has been found that a lower power consumption is obtained if the concentration of the concentrate stream is kept constant. The optimum concentration value of this stream will depend on the membranes, but can be varied to suit, for example, a district where even brackish water is scarce; in these conditions a higher concentration can be accepted, at the cost of a slight increase in power consumption, in order to economize the water used for blow-down. Each electrode compartment has a separate rinsing circuit, that for the anode compartment being, in the case of Tobruk, sea water, which of course emerges contaminated with chlorine. This can be removed as a gas and

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[1] The figures in brackets refer to the bibliography on page 329.

used for sterilization purposes if required. The rinse liquor for the cathode compartment is taken from the concentrate tank and dosed with a small quantity of hydrochloric acid to prevent the formation of calcium and magnesium hydroxide deposits. A good deal of attention has been given to the prevention of scale formation in the cathode compartment as well as in the membrane cells, and it is now claimed that this can be entirely prevented. One ingenious method which has been worked out for the prevention of scale in the electrode compartments involves a sodium hydroxide rinse for each electrode compartment, a sodium chloride rinse separating both electrode compartments from the first desalting compartment. At the cathode, calcium and magnesium ions are prevented from entering the sodium chloride compartment by the last membrane of the stack, which is positive; the current is carried by the sodium from the sodium chloride rinse so that the net result is a gain of sodium hydroxide in the cathode compartment and a loss of sodium chloride from the sodium chloride compartment. At the anode the reverse situation applies; there is a loss of sodium from the anode compartment, and the net result is a gain of sodium chloride in the sodium chloride compartment and a loss of sodium hydroxide in the anode compartment. By combining the sodium hydroxide rinses from the two electrodes, and also the two sodium chloride rinses, there is no theoretical loss of either chemical.

The best suggestion for the prevention of scale or deposits in membrane compartments is that, made originally by the South African Council for Scientific and Industrial Research, of the periodic reversal of current flow, so that the concentrate cells become in fact the diluate cells and vice-versa. This has heretofore raised the difficulty that the electrodes would also have to be changed because of excessive corrosion effects at the anode. This difficulty appears now to have been overcome by the introduction in the United Kingdom of platinum coated titanium electrodes which are extremely resistant to corrosion and show every sign of having an exceptionally long life.

Power requirements can vary between 7 and 25 kWh per 1,000 gallons according to the rate at which the water is desalted; the Tobruk plant is to be run at about 7 kWh per 1,000 gallons or a little less. The AC power requirement for pumping is constant and need not exceed 2 kWh per 1,000 gallons. The running costs of the plant other than power consumption include membrane replacement and depreciation. Developments are expected in the field of ion-exchange membranes, to which I will refer a little later, but using an estimate for membrane costs of 1s. 6d. to 2s. per 1,000 gallons of water treated (assuming a membrane cost of 2s. a square foot and a life of 18 months) and an annual amortization of 10 per cent including membrane costs, a cost has been arrived at of approximately 5s. per 1,000 gallons of water produced in the case of the Tobruk water, which is being desalted from about 4,600 ppm. to 500 ppm.

The use of batch operation should make it relatively easy to design multiple stack units for very much larger outputs. Stacks would be connected in parallel so that conditions can be made identical for each stack, thus offering the opportunity of providing a single set of instrumentation for a whole bank of stacks. At the other extreme, a design has now been produced for a single stack mounted as a self-contained unit on a small truck.

One other British firm, Permutit Ltd., has been engaged since 1950 on development work on its own design of electrodialysis unit, of which no details have as yet been disclosed. It is stated, however, that units under development have capacities of up to 1,000 gallons per hour, and are now undergoing field testing.

Finally in this connexion, brief reference might be made to the fact that the Low Temperature Research Station of the United Kingdom Department of Scientific and Industrial Research is also developing an electrodialysis unit of its own design for the demineralization of liquids of biological origin [6, 7].

Ion-exchange membranes

Since the economics of electrodialysis depend to a large extent on the cost, electrical resistance and selectivity of the ion-exchange membranes, at least a brief mention of developments in this field should be made here. There are three main types of ion-exchange membrane: the heterogeneous membrane, the interpolymer membrane and the homogeneous membrane. The heterogeneous membranes consist of a mixture of inert binder such as polyethylene and finely ground ion-exchange resin; they tend to suffer from micro-porosity, high initial cost and lack of dimensional stability, though this last property can be improved by using a fabric as supporting material. They also suffer from the inherent disadvantage that their electrical resistance can never be brought to such a low value as is possible with homogeneous membranes. Most of these disadvantages seem less pronounced in practice than might be expected, the major practical problem being low mechanical strength; however, it has been demonstrated that torn membranes can be repaired. Interpolymer membranes may be of the type in which a mixture of hydrophilic and hydrophobic polymers is cast as a film from a common solvent, or of the type in which a sheet of parchment is impregnated with polymerizable material which is subsequently polymerized within the parchment sheet. The first of these two kinds is restricted in scope because of the difficulty of finding suitable solvents, and those of the second type are chemically unstable but have the advantage of being cheap. Homogeneous membranes are obtained by various treatments which confer ion-exchange properties on a preformed polymer sheet. They are in many respects the most promising materials since they may be made with very low electrical resistances, reasonable chemical stability and good mechanical properties, and offer considerable scope for further research. Many laboratories all over the world are active in developing such membranes and naturally enough are not anxious to disclose in advance the progress they are making. In the United Kingdom the National Chemical Laboratory of the Department of Scientific and Industrial Research has, for several years, been investigating the properties of ion-exchange membranes and is now engaged in the development of new types of homogeneous membranes. These and other membranes are being evaluated by the Sondes Place Research Institute (one of the United Kingdom's few sponsored research institutions) under a joint programme sponsored by the Department of Scientific and Industrial Research and the United Kingdom National Research Development Corporation. The United Kingdom continues to take a share in the testing of membranes carried out on an international basis by the Netherlands organization TNO. Commercial firms are also known to be active in the field; for example, Permutit Ltd. have had heterogeneous membranes commercially available for some time and are known to be continuing developments, and Imperial Chemical Industries Ltd. have a new type of homogeneous membranes in the experimental stage.

DISTILLATION

Broadly speaking there are three main types of distillation plant: the conventional single or multiple effect plant in which steam derived from boiling brine in the first effect is condensed in the second effect where it gives up its latent heat to boil more salt water and so on, six or eight effects usually being the practical maximum dictated by economic considerations; vapour compression distillation in which the steam arising from the boiling brine is compressed, thus raising its temperature, and is recirculated so that the incoming brine is maintained in a boiling condition, the only continuing energy requirement being that of the compressor; and flash evaporation in which heated sea water is fed to reduced pressure chambers in which vapour is released and condensed. To summarize the characteristics of these distillation plants very briefly, the first type is the best known and, until very recently, all the biggest land-based plants have been of this kind; its major practical problem has been the prevention of scale formation on the heating surfaces. The second type, vapour compression distillation, offers the advantage of compactness and high fuel economy, though with relatively high capital cost for a given output; so far, only relatively small capacity units of this kind have been built. Flash evaporation, because of the lower pressures and temperatures used, may be so designed as largely to avoid scale formation, but fairly large vapour volumes must be handled.

SCALE PREVENTION

In the United Kingdom, research and development work in all these processes is in progress both in industry and in government laboratories. The Admiralty Materials Laboratory in particular carries on research into some of the fundamental aspects of the distillation process. Work was begun there some years ago with a study of scale formation. There are in general three forms of scale which may deposit on the heating surfaces of an evaporator and on the inside of the evaporator shell and which cause by so doing a fairly rapid fall in the heat transfer rates and in the output of the evaporator. Regular cessation of operation for the cleaning of these surfaces had always been regarded as unavoidable and in designing a plant for a given rated output allowance had always to be made for this factor. The three types of scale are calcium sulphate, calcium carbonate and magnesium hydroxide. It is now known that sulphate scale is deposited as a result of a concentrating film mechanism. The deposition of the other two types of scale is governed by the two following equilibria:

$$2HCO_3 \rightleftharpoons CO_3'' + CO_2 + H_2O$$
$$CO_3'' + H_2O \rightleftharpoons 2OH + CO_2$$

It was established fairly early in the work at the Admiralty Materials Laboratory that, in accordance with these mechanisms, the heating of sea water at clean surfaces will involve a rapid rise in *p*H with the evolution of CO_2 and the deposition of a carbonate scale. Higher temperatures encourage the formation of an increasing proportion of hydroxide scale. One method of preventing the formation of scale is to use acid treatments which will prevent this rise in alkalinity. Trials were carried out with several different acid materials and also with an electrolytic cell using sacrificial aluminium anodes. As is well known, the treatment using ferric chloride [5], is in established commercial practice. A dosage rate of approximately 0.18 lb. of anhydrous ferric chloride per ton of sea water feed is employed, the cost working out at approximately 1s. per 1,000 imperial gallons of fresh water produced. The potential disadvantage of this treatment is, of course, that there is a risk of corrosion effects if the dose rate is not carefully controlled and that there may be an increased amount of foaming on the surface of the brine in the evaporator. Either of these effects could obviously be extremely undesirable but in practice if they are kept under reasonably careful control it seems to be perfectly possible to run the evaporator at its full rated output almost indefinitely, though not necessarily, because of the foaming, with the heating coils fully submerged. It should also be pointed out that ferric chloride is deliquescent and corrosive so that it must be stored in steel drums lined with polyethylene and handled with reasonable care. More recently the firm concerned with this development has designed an electrolytic cell with sacrificial iron anodes to replace direct dosage with ferric chloride. This technique offers the advantage that only iron anodes have to be transported instead of ferric chloride and that the dose rates can be closely and readily controlled by the variation of the current supplied to the cells. The capital cost of the installation has been quoted as 0.7 per cent of the capital cost of a sextuple effect distillation plant.

The Admiralty Materials Laboratory proceeded to the development of a treatment which was intended to modify the physical nature of the scale in such a way that hard and adherent scale was unlikely to form, the material used for the treatment being itself non-corrosive. The compound resulting from this work included a surface active agent (the sodium salt of di-naphthyl methane di-sulphonic acid) which restrains crystal growth and layer formation and facilitates the discharge of the deposit as a fine suspension, and a chelating agent (ethylene-diamine tetra-acetic acid) which renders the traces of copper in the water chemically unavailable thus, so it is thought, preventing the initial bond which forms between the scale and the copper of the heating coil and tends to be composed of a magnesium/copper complex. This compound was subjected to extensive trials and a 50/50 mixture was put into regular use under the name of Admiralty Evaporator Compound. It was found that the output of the evaporator could be maintained for very much longer periods with the use of this compound. The more frequently the "cold shocking" procedure was carried out, the closer could the output be kept to the clean coil condition.

A foam preventative agent has now been added to the Admiralty evaporator compound; foam naturally forms under normal conditions in evaporators and because of this the coils cannot be kept immersed in brine without the risk of salt carry-over with the distillate. The anti-foam agent finally selected was polyethylene glycol stearate in a proportion of 0.0003 per cent by weight on the sea water feed. Extensive trials indicated that increases of output of the order of 40 per cent could be achieved by this means, with a reduction in priming and with increased purity of the distilled water.

DROPWISE CONDENSATION PROMOTION

After the development of these scale-prevention materials, work at the Admiralty Materials Laboratory turned to the study of rather more fundamental aspects of distillation. It was already known that if the steam which was being used for heating the sea water could be made to condense on the metal surface separating the two media in the form of droplets rather than as a more or less uniform film, a much higher rate of transfer of heat across the metal surface could be achieved. The use of silicones for this purpose was investigated but they proved unsatisfactory for various reasons. More recently, two groups of compounds have been found which do have a marked influence on the form of condensation and which show good prospects of being practicable in distillation equipment. These compounds are first coal extracts, developed by the British Coal Utilization Research Association, of which little is known except that certain fractions of coal, obtained by solvent extraction, are able to bring about dropwise condensation (an attempt is being made to isolate the active ingredients); secondly, a large range of compounds in which long hydrocarbon chains are attached to groups containing sulphur or selenium. It has been suggested by Blackman [2] that the sulphur or selenium of the compound enables a chemical bond to be made with the copper of the heat transfer surface and that the hydrocarbon chains form a hydrophobic molecular layer on which the steam condenses in the form of droplets. A few of the compounds in the second group are now available commercially in pilot quantities. In early trials these compounds were applied direct to the condenser tubes but it has now been established that injection of the promoter in the heating steam is satisfactory. The normal clean coil over-all rates of heat transfer obtained with this experimental equipment were of the order of 1,500 BTU/sq.ft./°F./hr. With the use of these dropwise promoters over-all heat transfer values were obtained which ranged from 2,200 BTU/sq.ft./°F./hr. to almost 3,000 BTU/sq.ft./°F./hr.

There was an indication in the experimental results, however, that beyond a certain point (roughly equivalent to a *steam side coefficient* of about 11,000 BTU/sq.ft./°F./hr. for the apparatus and conditions used), further increase in the total heat flux does not in fact take place; this may be due to flooding on the steam side. The results also indicate that for an evaporator designed to use only a low heat flux, the use of promoters would probably not be justified since in this region the effect on the rate of heat transfer would not be very marked. However, for evaporators in which operating conditions are suitable, calculations have indicated that the reduction in heat transfer surface which may be obtained by the use of promoters might represent a reduction in total capital cost of as much as 30 per cent. It is of interest in this connexion that the paper reporting some of the detailed results of this work [3] records results of a trial carried out on a 25-ton per day evaporator operating under boiling conditions but fitted with self-shocking elements of the submerged type which gave a moderate circulation to the brine. A normal output of 13 tons per day after half the heating elements were removed was increased to 19 ½ tons per day by the use of dropwise promoters. An increase of heating steam pressure (but still within the makers' specification) raised the output to as much as 26 tons per day when promoted elements were used. In this case the heating elements were of monel metal and therefore even better results were to be expected with copper.

DESIGN DEVELOPMENTS

The design and development field in industry currently presents a scene of considerable change and activity as several new departures challenge the supremacy of the long-established multiple-effect submerged coil evaporator. A considerable choice is now available to meet the differing requirements for portable, compact, high fuel-economy vapour-compression plants for remote areas, with minimum supply and maintenance demands and a wide range of outputs; for large size land-based plants with a minimum total cost per 1,000 gallons of fresh water produced; for plants using waste heat; and for shipboard operation.

Flexible heat transfer surfaces, which aim at scale removal by cold shocking without feed water treatment, have been developed by two firms (Caird and Rayner and G. & J. Weir); the motion of the element itself during normal operation is claimed to some extent to inhibit the formation of scale, and the cold shocking procedure is considerably more efficient, so that output is well maintained over at least 1,000 hours. Heat transfer rates of the order of 50 per cent greater than those obtained with submerged coils are claimed. One of the designs is claimed to produce a fairly rapid circulation of brine across its surface so that the chance of a concentrating film mechanism producing a calcium sulphate scale is reduced.

A "package" design of an eight-stage multiple effect plant has been produced which is fabricated in steel in one large unit. Each of the eight stages is designed for low retention times, low temperature differences, and has the tube distribution designed to give maximum transmission rates under these conditions. It will also, of course, have the advantage that the capital cost will be low compared with the cost of independent units with interconnecting pipes and that the "package" design can also be shipped flat as plates.

In the vapour compression field a new design has entered the market in the form of a self-contained, skid mounted, diesel driven unit designed by Davey, Paxman & Co. Ltd. A minimum capacity of 40,000 gallons per day is planned for, and since at this output the centrifugal compressor employed is operating at the lower end of its economic range, outputs up to 400,000 gallons per day can be provided from a plant driven by a single diesel engine. Initial warming-up is achieved by a separate burner using diesel fuel, and scale formation is controlled by a continuous and automatic cold shocking sequence in conjunction with a proper choice of operation conditions. By these means the plant is kept independent of external supplies of electric power and feed treatment chemicals.

Perhaps the most significant design development for many years is that recently announced by Silver [8] of G. & J. Weir's and Frankel [1] of Richardsons, Westgarth & Company Limited who have been independently responsible for new types of flash evaporating plant. The essential feature of these designs is due to the realization that with a flash evaporator designed for a given specific heat consumption (i.e. BTU/lb. of distillate produced) the area of heating surface required per lb. of distillate produced can be reduced by increasing the number of stages. The evaporator designer has in consequence to find the economic balance between the cost of producing a plant with a large number of stages and the material cost of relatively expensive copper alloy tubes used for the heating surface. The above factor has resulted in typical British designs being based on the use of a relatively large number of stages; for a gained output ratio of 8 : 1, i.e. a specific heat consumption of 125 BTU/lb. of distillate, not less than 15–20 stages would be used.

The flash evaporator lends itself to the construction of large output plants more readily than the conventional submerged tube type, the units being of a compact design with a minimum of interconnecting pipework. As a consequence there has been a substantial reduction in the cost of sea water distillation plant and it is claimed that the introduction of the flash evaporator has brought about a saving in capital cost of some 40–60 per cent as compared with conventional submerged coil plant of the same output. This improvement in capital cost is more readily realized with plants having a high performance ratio, i.e. low specific heat consumption. Calculations based on the standardized cost estimate procedure developed by the U.S. Department of the Interior indicate that for plants with large capacity a cost of 6s.8d. per 1,000 imperial gallons can be obtained. The first evaporator of this type, of a capacity of 500,000 gallons per day, is currently being installed in the Island of Guernsey (in the English Channel).

Obviously, it would be desirable to reduce fuel costs in distillation where possible by the use of any source of waste heat. An interesting recent development in this direction has been the combination of a water-cooled diesel engine (Mirrlees, Bickerton & Day Limited) and a flash type sea water distillation plant. The system consists of a pressurized water-cooling jacket for the engine in which the cooling water is heated over the temperature range of approximately 225°F. to 236°F. The hot water is cooled from 236°F. to 225°F. by flashing in a suitable chamber and is then returned to the engine jacket by means of a circulating pump. In addition, provision is made to pass the engine exhaust gases through tubes submerged below the water level in the flash chamber, additional heat being thereby recovered. This combination produces steam, if necessary, at a pressure up to 5 psig. the rate being approximately 2 lb. of steam per horse power. The most economical performance range for a flash evaporator lies between 3 and 8 lb. of distillate per lb. of heating steam and therefore it is possible to produce 6–16 lb./hr. of distillate per horse power. A diesel power-station comprising 3 × 3,500 h.p. diesel-driven generating sets would produce in combination with a flash evaporator 400,000 imperial gallons per day of distillate at almost negligible running costs.

OTHER PROCESSES

Solar distillation

At least one solar still has been designed by a United Kingdom worker, the experimental work being carried out in Cyprus. First experiments with a traditional "greenhouse" type of still [4] showed that the main difficulty was to obtain a vapour-tight enclosure; the loss of evaporated water when the still was run on a closed circuit was of the order of 40–50 per cent. Many attempts were made to maintain a vapour seal but nothing was found which was sufficiently cheap and simple to justify a large-scale trial. Other workers have reported the same difficulty.

More recent experiments had the object of providing improved condensing conditions on cool surfaces, so that the vapour pressure in the enclosure would be reduced and the loss of vapour prevented. A series of small stills was made in which the solar energy was admitted through a sheet of window glass set in a galvanized steel sheet envelope. The brine tray was suspended in the centre of the envelope so that the vapour could circulate round the sides of the tray and the condensate could run freely to the space below the tray. Using a 30°–60° envelope, with the glass facing south on the 30° slope, the 60° slope received a minimum of radiation and was the principal condensing surface. An internal deflector plate was arranged to assist in a regular circulation of vapour in the still. This would serve as a reflector to increase the radiation received in the brine tray when the sun was at a low altitude. This series of stills gave encouraging results. The first, with the circulating passages blocked off gave the same yield as the "greenhouse" type. By opening the circulating passages the yield was raised by 10–12 per cent, and by adding cooling fins to the 60° slope to assist in removing the latent heat of condensation a further 12–15 per cent increase in yield was obtained. This model was run in a closed circuit for several months and the "make-up" brine needed to maintain the level was negligible. A pilot scale model was then constructed, which gave the results anticipated from the small scale series, and no difficulty is expected in operating a still of this type. The yield obtained in Cyprus for a year's operation was 27 gallons for each square foot of evaporating tray and from the records obtained over a full year's operation it should be possible to estimate the yield for places in different latitudes, provided there are records of the hours of sunshine.

RÉSUMÉ

Progrès effectués au Royaume-Uni en matière de déminéralisation des eaux salines ou saumâtres (D. Neville-Jones)

L'auteur déclare que les spécialistes du Royaume-Uni s'intéressent activement à toutes les techniques de déminéralisation actuellement connues; à leur sens, l'électrodialyse s'imposera, sur le plan commercial, comme le procédé le plus économique pour les eaux moins salées que l'eau de mer. En Libye, une installation mettant en œuvre un procédé de distillation en discontinu a permis d'obtenir de l'eau douce à un prix d'environ 5 shillings par millier de gallons (un gallon vaut 4,5 litres). Le problème consistant à empêcher la formation de dépôts tant dans le compartiment cathodique que dans les cellules à membranes, semble maintenant entièrement résolu. Des recherches approfondies sont en cours sur les membranes, notamment en vue de mettre au point de nouveaux types de membranes homogènes.

Des recherches ont été entreprises sur certains des aspects fondamentaux du processus de distillation; on a étudié en particulier la formation des dépôts tout d'abord en appliquant des traitements à l'acide, puis à l'aide d'un composé (*Admiralty Evaporator Compound*) comprenant un agent actif en surface, un agent de chélation et un agent anti-écume. Il est apparu que deux groupes de composés ont une nette influence sur les modalités de la condensation et peuvent provoquer une condensation en gouttelettes: d'une part, des extraits de charbon produits par la British Coal Utilisation Research Association, et, de l'autre, une gamme étendue de composés où de longues chaînes d'hydrocarbures sont liées à des groupes contenant du soufre ou du sélénium.

D'importants progrès ont été réalisés dans le domaine de la mise au point des appareils, et il en existe maintenant de types très divers permettant de répondre aux différents besoins. C'est ainsi qu'on a produit des surfaces souples de transfert de chaleur visant à éliminer les dépôts par "choc froid" sans traiter l'eau d'alimentation; un grand appareil transportable en acier, à distillation fractionnée en huit stades a été construit. En ce qui concerne la distillation par thermocompression, un appareil autonome, monté sur patins et actionné par un moteur Diesel, a été mis en vente. Plus importante encore peut-être est la mise au point de nouveaux types d'installation à évaporation instantanée, dont certains ont une capacité de production considérable. On estime que les investissements nécessaires sont de 40 à 60 % moins élevés pour ces évaporateurs que pour des installations de type classique à enroulement immergé d'un débit comparable. D'autre part, on parvient à réduire les dépenses de combustible dans des proportions appréciables en récupérant la chaleur perdue, grâce à la combinaison d'un moteur Diesel refroidi à l'eau et d'un appareil de distillation de l'eau de mer à évaporation instantanée.

L'auteur décrit enfin un alambic solaire dont le plan a été établi au Royaume-Uni, et qui est expérimenté à Chypre. La principale difficulté consistait à obtenir un espace clos imperméable à la vapeur; des expériences plus récentes ont eu pour but d'améliorer les conditions de condensation sur des surfaces fraîches, afin de réduire la pression de la vapeur dans l'espace clos pour empêcher les pertes de vapeur.

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TRAITEMENT ET UTILISATION DES EAUX SAUMÂTRES DANS LES RÉGIONS ARIDES

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LE TRAITEMENT DES EAUX SAUMÂTRES

Le choix du traitement à appliquer à une eau saumâtre est déterminé par la nature initiale de l'eau, par les conditions locales au sens le plus général et par la définition des besoins à satisfaire.

C'est là une vérité d'évidence, mais il est bon d'y insister, car elle est assez souvent oubliée par les chercheurs et par les auteurs qui comparent les différents procédés de traitement.

Le traiteur d'eau peut arriver à connaître d'une façon satisfaisante par l'analyse, la nature de l'eau, par une étude approfondie, les conditions locales. En revanche, il est généralement peu compétent en ce qui concerne la nature réelle et l'étendue des besoins de l'utilisateur: il doit s'en remettre aux exigences de ce dernier.

Dans le domaine des eaux saumâtres, la réponse de l'utilisateur au traiteur d'eau a été, en gros, jusqu'à présent, l'exigence d'une déminéralisation totale ou partielle jusqu'à une limite assez poussée.

L'utilisateur exige, somme toute, que le traiteur lui fournisse à partir de l'eau saumâtre, une eau d'une minéralisation voisine de celle des eaux européennes ou des eaux des régions favorisées de la frange méditerranéenne de l'Afrique.

Il est bon de remarquer que cette façon de ramener les besoins à des normes européennes (ou plus exactement de pays tempérés) n'est pas du tout adoptée par le même utilisateur dans d'autres domaines. Par exemple, il s'appliquera à rechercher des façons culturales nouvelles bien adaptées au climat, aux eaux naturelles, au sol. Il cherchera à sélectionner des espèces végétales ou animales, il en modifiera le mode de culture ou d'élevage.

Le traitement des eaux saumâtres étant ainsi ramené par la volonté des utilisateurs à une déminéralisation totale ou presque, trois procédés ont été plus particulièrement étudiés en Algérie et au Sahara: les échangeurs d'ions; la distillation solaire; l'électrodialyse.

Tous ces travaux ont abouti à des résultats pratiques satisfaisants qui se sont traduits par une diffusion d'appareils nouveaux facilitant les conditions de vie et de travail dans les régions arides.

Ils ont fait l'objet de communications lors de congrès nationaux et internationaux récents. De plus, ils relèvent de disciplines techniques qui seront traitées par des participants au présent colloque.

Aussi, dans le présent exposé, se bornera-t-on à rappeler très rapidement les résultats pratiques obtenus.

LES ÉCHANGEURS D'IONS

Le procédé des échangeurs d'ions est connu depuis longtemps par ses applications industrielles pour la préparation d'eaux très pures à partir d'eaux de faible minéralisation.

Il était réputé inapplicable à la déminéralisation des eaux saumâtres pour des raisons d'ordre économique, les critères de jugement adoptés étant ceux en usage dans les régions développées de la zone tempérée.

Un examen plus attentif de la question a montré qu'on pouvait, d'une part, diminuer son prix de revient (dans une faible mesure, il est vrai) et d'autre part le rendre d'un emploi particulièrement intéressant dans certains cas.

Si l'on fait abstraction des opérations de régénération des résines, la déminéralisation par échangeurs d'ions est d'une remarquable simplicité puisqu'elle se résume à une percolation de l'eau au travers d'un lit granuleux.

Les résines, pour l'emploi, ont été mises dans de petits containers légers en matière plastique, les opérations de régénération étant centralisées en un point unique, centre de gravité des différents points d'utilisation.

La suppression d'une enveloppe usinée et complexe et la suppression de tous les appareillages, sauf un, de régénération, ont permis de diminuer sensiblement le prix de revient. Il a fallu sélectionner des résines adaptées à la minéralisation élevée des eaux brutes et déterminer les modes d'épuisement et de régénération les plus efficaces.

Le résultat a été la création d'un outil commode destiné à l'équipement de petits groupes humains mobiles ou semi-mobiles: équipes de prospection géologiques et géophysiques; équipes d'études hydrologiques et pédologiques; chantiers.

Il ne faut d'ailleurs pas croire que l'utilisation de cette eau déminéralisée se soit trouvée réservée, par la force des choses, aux seuls éléments d'origine européenne effectuant des séjours, pour travaux techniques, dans les régions arides.

En fait, dans les chantiers en particulier, l'ouvrier autochtone, réputé "adapté" à l'ingestion des eaux saumâtres, s'est rapidement mis à éprouver des besoins très analogues à ceux de ses camarades européens dès qu'il a abandonné son mode de vie ancestral pour partager l'activité de ces derniers.

A titre d'exemple on peut donner quelques chiffres concernant les résultats obtenus avec un groupe de trois petits containers pesant au total 90 kg.

	Exemple 1	Exemple 2	Exemple 3
Qualité de l'eau brute			
Dureté (° français)	214°	333°	510°
Résidu sec (mg/l)	4 780	7 815	13 980
Volume d'eau déminéralisée obtenu (litres)	600	325	150
Qualité de l'eau déminéralisée			
Dureté	3°	8°	10°
Résidu sec	420	608	331

La formule de l'échangeur d'ions connaît au Sahara un succès certain en raison de sa commodité d'emploi, de la réduction sensible des servitudes de transport (poids, encombrement) qu'elle procure, et de l'accroissement considérable qu'elle donne dans le domaine de la sécurité pour le personnel et le matériel (batteries, radiateurs, etc.) se déplaçant dans des régions disposant de puits saumâtres.

Bien qu'elle reste d'un emploi onéreux et ne puisse s'appliquer à des eaux d'une salure nettement supérieure à 8 g/l, la formule ne méritait pas d'être rejetée *a priori*. Une étude approfondie des conditions locales et des besoins à satisfaire a permis de mettre au point un outil supplémentaire à l'usage des équipes portant les premiers germes du développement technique dans les régions arides.

LA DISTILLATION SOLAIRE

En Afrique du Nord, de très intéressants résultats pratiques ont été obtenus dans le domaine du petit distillateur solaire transportable et préfabriqué.

On ne répétera pas ici ce qui a été dit lors de congrès et colloques récents. Il faut souligner cependant qu'en Afrique du Nord la distillation solaire s'est créé un marché commercial.

Cette diffusion dans le public qui doit être un fait unique au monde démontre bien que la distillation solaire mérite l'attention qu'on lui porte et qu'elle répond à un besoin réel.

Aujourd'hui, en une centaine de points de l'Afrique du Nord et du désert saharien (y compris sa frange tchadienne et sénégalaise) des distillateurs solaires sont en service et fournissent de l'eau distillée pour couvrir des besoins: de boisson; médicaux et pharmaceutiques; techniques (batteries électriques, eau de refroidissement de moteurs thermiques).

Là encore, malgré le prix de revient encore trop élevé de l'eau ainsi obtenue, une détermination exacte des besoins locaux et une étude serrée des problèmes annexes (étude faite *in situ*) a permis de rendre viable un procédé qui, mis en œuvre autrement, à une échelle trop grande par exemple, ou encore en tenant insuffisamment compte des conditions d'exploitation locales, n'aurait pu intéresser le public et ne serait pas sorti du domaine des recherches gouvernementales subventionnées.

Cette attitude de praticien ne s'oppose absolument pas aux études dites de base et qui ne peuvent que très difficilement échapper au domaine gouvernemental subventionné. Au contraire, elle tient simplement à bien mettre en évidence la nécessité de mener simultanément les études d'application pratique et les études fondamentales.

L'ÉLECTRODIALYSE A MEMBRANES SÉLECTIVES

Il faut souligner que ce procédé constitue un important progrès pour le dessalement partiel des eaux titrant moins de 20 g/l et qu'au-delà de cette salure, il doit rester compétitif suivant les circonstances avec la distillation thermique la plus perfectionnée et avec le dessalement par congélation quand ce dernier sera mis au point.

Le principe de l'électrodialyse et les modalités de son application sont maintenant bien connus, tout au moins tant qu'il s'agit d'une déminéralisation partielle globale sans recherche d'une déminéralisation sélective par rapport à certains ions.

Nous pensons bien, avec nos installations industrielles réalisées au Sahara, mettre en évidence que certains facteurs annexes — quelquefois inattendus, tels que: la température ambiante, celle de l'eau, la sécheresse de l'air, l'effet des vents de sable sur le matériel électrique, voire l'influence de la présence de certains ions gênants dans l'eau traitée — peuvent prendre, si l'on se risque à les ignorer, une importance pratique aussi grande que les processus de base eux-mêmes.

Là encore, une connaissance approfondie des conditions locales est indispensable à une application réellement efficace du procédé.

LIMITES D'APPLICATION DES TRAITEMENTS ACTUELS

Si l'on ajoute la distillation thermique à thermocompression aux procédés énumérés plus haut on aura pratiquement épuisé la liste des procédés susceptibles d'être réellement appliqués à l'heure actuelle au traitement des eaux saumâtres. Cette limitation ne constitue pas une réserve en ce qui concerne d'autres procédés actuellement à l'étude.

On a souvent discuté sur la prééminence de certains d'entre eux. Une telle prééminence peut exister suivant les conditions locales.

En ce qui concerne les régions arides, en réservant le cas des points disposant à proximité immédiate de combustible sans valeur marchande, tel le bunker-lourd, on peut affirmer que les différents procédés sont complémentaires. On peut également ajouter que les prix de revient ainsi que les dépenses en énergie restent encore beaucoup trop au-dessus du niveau souhaitable.

Les procédés sont à la limite d'application pratique pour la production d'eau de boisson; peu d'industries pourraient faire appel aux moins onéreux d'entre eux pour la fourniture d'eaux industrielles; il est exclu de les utiliser pour les besoins agricoles ou l'abreuvage abondant du bétail.

En ce qui concerne les eaux de boisson on peut essayer de délimiter les zones d'application en fonction du volume d'eau consommé et de la salure initiale de l'eau traitée:

Qualité de l'eau brute (salure)	Utilisateur mobile	Utilisateur fixe
Besoins inférieurs à 1000 litres par jour		
Inf. à 8 g/l	Échangeur d'ions *ou* distillateur solaire transportable	Distillateur solaire fixe
Sup. à 8 g/l	Distillateur solaire transportable	Distillateur solaire fixe
Besoins supérieurs à 1000 litres par jour		
Inf. à 20 g/l	Électrodialyse, appareil transportable	Électrodialyse, appareil fixe
Sup. à 20 g/l	Électrodialyse, appareil transportable *ou* distillateur à thermocompression transportable	Électrodialyse *ou* distillateur à thermocompression

Il reste bien entendu qu'en raison de l'évolution des techniques, les indications ci-dessus n'ont qu'une valeur limitée dans le temps. Elles sont plus spécialement valables dans les conditions sahariennes actuelles.

ÉLABORATION D'UNE NOUVELLE MÉTHODE DE TRAVAIL

Tous les procédés utilisés, même les plus rentables du point de vue énergétique comme l'électrodialyse, conduisent, on l'a vu, à des prix de revient trop élevés.

Il faut donc poursuivre le perfectionnement des procédés connus et chercher à en mettre d'autres au point.

Cependant, on peut se poser la question de savoir s'il n'y aurait pas lieu d'aborder le problème autrement, c'est-à-dire en définissant d'une autre façon les besoins réels des utilisateurs.

Prenons par exemple un travailleur de force dans une région aride et chaude. Il va faire transiter à travers son corps 10 litres et plus d'eau par jour.

On exige pour l'abreuver la fourniture d'une eau faiblement minéralisée théoriquement afin d'éviter certains troubles digestifs et de faciliter l'ingestion du liquide en masquant son goût désagréable, etc.

Simultanément afin de compenser les pertes minérales de l'organisme par sudation, élimination urinaire, etc., on lui fera ingérer chaque jour quelques grammes de sels minéraux, sous forme de comprimés.

N'y a-t-il pas là une certaine contradiction? N'existe-t-il pas une solution de compromis? Il est vraisemblable que le complexe ionique naturel de l'eau saumâtre est souvent nocif. Mais il n'est pas impossible qu'une modification, peut-être légère, de la composition ionique, aussi bien en quantité qu'en qualité, de l'eau naturelle permette de disposer d'une eau, peut-être pas très agréable au goût, mais tout à fait acceptable du point de vue médical.

Ce qui est certain, c'est qu'une simple et partielle transposition ionique est souvent bien moins onéreuse, du point de vue de l'énergie consommée, qu'une déminéralisation partielle poussée.

Prenons un autre exemple. L'irrigation dans les régions arides demande une quantité considérable d'eau, ce qui rend inapplicables aux besoins agricoles les procédés actuels de déminéralisation.

Cependant, si l'on dresse le bilan d'utilisation de l'eau d'irrigation, on s'aperçoit que la plus grande partie de cette eau sert à lessiver le sol afin qu'il ne se sale pas en raison des dépôts salins provenant de l'eau évaporée. Au travers de la plante elle-même ne transite qu'une très faible quantité d'eau. Si l'on voulait aller jusqu'au paradoxe, on pourrait presque dire que l'eau d'irrigation, dans les pays arides à forte évaporation, est utilisée à diluer les dépôts salins provenant de sa propre évaporation.

La véritable solution au problème de l'irrigation ne réside-t-elle pas dans la diminution du taux évaporatoire du sol près du pied irrigué et au niveau des feuilles? Si une telle diminution était acquise par un procédé à déterminer, la quantité d'eau d'irrigation nécessaire rapportée au poids de la récolte pourrait devenir suffisamment faible pour accepter des traitements classiques de déminéralisation partielle.

Pour montrer que cette façon peu orthodoxe d'aborder le problème du traitement et de l'utilisation des eaux saumâtres n'est pas utopique, même dans l'état de choses actuel, on peut donner deux illustrations techniques.

ADOUCISSEMENT PARTIEL DE L'EAU DURE PAR DES IONS ALCALINS PROVENANT D'ELLE-MÊME

Considérons une eau très dure et très minéralisée. Supposons qu'elle soit soumise à l'effet concentrant d'une évaporation. La concentration des différents ions ne sera pas proportionnelle du fait des différences de solubilité des composés minéraux. Les sels alcalino-terreux étant très généralement beaucoup moins solubles que les sels de sodium (ou alcalins), à partir d'un certain degré de concentration, les teneurs relatives en sels alcalins vont s'accroître très rapidement comparativement à celles des alcalino-terreux.

On conçoit qu'il est théoriquement possible, à partir d'un certain moment de l'évolution du concentrat, de l'utiliser comme saumure de régénération pour des échangeurs d'ions servant à l'adoucissement alcalin de l'eau non concentrée.

Ce processus, théoriquement possible, l'est aussi pratiquement.

L'irrigation dans beaucoup de régions algériennes et sahariennes se pratique avec un drainage concomitant. Les eaux de drainage subissent l'effet de concentration par évaporation au cours de leur trajet dans les terres irriguées et pendant leur séjour dans les canaux d'irrigation. La composition ionique de ces eaux est telle (tout au moins à certaines périodes de l'année) qu'elles peuvent servir à la régénération d'échangeurs d'ions utilisés pour adoucir des eaux d'une qualité identique à celle des eaux d'irrigation.

Ces opérations d'adoucissement et de régénération ont été pratiquement faites de façon à démontrer que ce n'est pas là une vue de l'esprit.

	Exemple numérique n° 1		Exemple numérique n° 2	
	Sodium	Dureté[1]	Sodium	Dureté[1]
	mg/l		mg/l	
Eau naturelle	911	188°	273	64°
Eau concentrée	7 665	822°	3 265	345°
Eau adoucie		48°		10°

[1] En degrés hydrotimétriques français.

La saumure de régénération était pratiquement gratuite (aux frais de pompage et de filtration près): on la prenait simplement dans le canal principal de drainage.

A défaut de drainage, on peut faire concentrer une fraction d'une eau dans une lagune artificielle afin d'adoucir l'autre fraction. Les taux d'évaporation étant considérables et le terrain d'un prix réduit dans les régions arides, on a là un moyen commode et relativement peu onéreux de créer les moyens nécessaires à l'obtention de saumure de régénération.

Quel peut être l'intérêt du procédé? Du point de vue des applications domestiques et industrielles, il est évident. L'emploi d'une eau de près de 200° de dureté est une sujétion très lourde. Son adoucissement avant injection dans le réseau de distribution publique est souhaitable.

L'adoucissement ne change pratiquement pas la valeur élevée de la minéralisation totale, mais il en change partiellement la composition en faisant disparaître une grande partie des ions calcium et magnésium pour les remplacer par des ions alcalins, principalement sodium et un peu potassium.

Il arrive que l'ingestion d'une eau contenant 3 à 5 g/l de sels alcalins, principalement sodiques, surtout comme cela peut se produire lorsque les anions chlore sont plus abondants que les anions sulfate, soit beaucoup moins désagréable que celle d'une solution chlorurée calcique et magnésienne.

L'adoucissement, rendant l'eau plus agréable à ingérer, peut remplacer la déminéralisation, ou rendre les gens moins exigeants sur les limites d'une déminéralisation partielle.

Mais quel sera l'avis médical? L'eau sera-t-elle plus ou moins nocive après adoucissement? La réponse manque et le traiteur d'eau ne sait pas si la voie qu'il cherche à ouvrir est féconde ou si au contraire elle ne va pas aboutir à un interdit médical.

D'autres voies analogues pourraient être explorées tant dans le domaine de l'alimentation humaine que dans celui des besoins agricoles.

Par exemple y aurait-il intérêt à enrichir en calcium les eaux d'irrigation sodiques ou au contraire le calcium est-il un élément nocif supplémentaire? Les réponses sont diverses et souvent contradictoires. L'idée même que le traiteur d'eau pourrait se mettre à sa disposition autrement qu'en déminéralisant des eaux trop chargées en sels n'est pas venue à l'esprit de l'utilisateur. Il n'est pas prêt à donner une réponse concernant les modifications souhaitables dans la minéralisation des eaux qu'il cherche à utiliser.

DISPOSITIF DE CULTURE DE F. TROMBE ET M. FOEX

MM. Trombe et Foex, dont les travaux sur l'utilisation de l'énergie solaire sont par ailleurs fort connus, ont récemment proposé de créer une culture en régions arides en établissant au voisinage des plantes cultivées un microclimat humide, chaud, mais aux variations de température relativement tempérées par la présence, au sein d'une sorte de serre, de masses d'eau saumâtres recevant l'énergie solaire tombant sur la serre et portant ombre sur la partie basse où se fait la culture.

Les personnes intéressées par le détail des points de vue exposés pourront se reporter au procès-verbal de la séance du 30 octobre 1957 de l'Académie d'agriculture de France.

C'est là une illustration remarquable de la nouvelle méthode de travail qu'il faudrait systématiquement adopter.

Alors que la distillation solaire conduit à des prix de revient à peine admissibles pour la production de faibles quantités d'eau de boisson, la méthode de culture précitée rend possible par un moyen indirect l'utilisation de la distillation solaire pour satisfaire des besoins d'irrigation en région aride.

Le bilan précis de l'opération reste encore à établir. Il semble bien cependant qu'appliqué à des cultures maraîchères, le procédé ne soit pas économiquement absurde. Une expérimentation pratique est en train de s'organiser en Algérie pour bien préciser les difficultés à surmonter.

L'apparition sur le marché de films étanches ou transparents peu onéreux et doués d'une bonne résistance aux intempéries facilitera certainement la solution des problèmes de construction qui se poseront.

On peut d'ailleurs penser qu'un chauffage séparé en lagunes protégées contre l'évaporation à l'aide de films chimiques monomoléculaires et l'envoi par la suite de cette eau tiédie dans des serres simplifiées en matière plastique alternativement disposées en panneaux transparents et opaques constitueraient une première ébauche de solution pratique.

CONCLUSION

Le traiteur d'eau travaille pour l'instant dans un cadre trop étroit et il bute sur des difficultés provenant du taux de consommation d'énergie ou du prix de revient global.

Il faut certes s'appliquer à surmonter ces difficultés en améliorant les procédés actuellement applicables et en cherchant à mettre au point de nouveaux procédés. Cependant il faudrait simultanément chercher à les tourner soit en obtenant une meilleure définition des besoins réels des utilisateurs soit en modifiant considérablement les conditions d'emploi de l'eau dans les régions arides.

Deux voies différentes s'ouvrent ainsi aux chercheurs. La première est celle qui conduit à une meilleure connaissance des métabolismes végétaux, animaux et humains; elle exige la mise en route de recherches de base approfondies.

L'autre voie est celle de l'invention de dispositifs ingénieux tendant à s'opposer au gaspillage considérable d'énergie qui se produit dans les zones arides par disparition de l'eau qu'on cherche à utiliser dans une atmosphère trop sèche. Elle exige la mise au point de dispositifs techniques peu onéreux et bien adaptés à l'application d'une idée de départ fructueuse.

Cette façon de penser va dans le sens de la nature: il suffit d'observer l'adaptation aux conditions locales des plantes et des animaux des régions arides pour comprendre que l'application directe de l'énergie dont l'homme dispose au dessalement, on peut dire brutal, des eaux naturelles pour utiliser par la suite, sans ménagement, l'eau dessalée suivant des méthodes empruntées à des régions tempérées, n'est peut être pas la façon la plus équilibrée de procéder.

La recherche d'un biais, d'un compromis avec la nature, doit être difficile; on peut penser cependant qu'elle apportera finalement le moyen de surmonter les difficultés actuelles d'une façon définitive en permettant simultanément de diminuer les taux de consommation *spécifique* en eau dessalée, le degré de dessalement exigé et le prix spécifique du dessalement.

Cette recherche devrait être systématiquement introduite dans tout programme portant sur le dessalement des eaux.

SUMMARY

The treatment and utilization of brackish water in arid regions (Cyril Gomella)

Brackish water constitutes a large proportion of the water resources of Algeria and the Sahara, and in certain regions the only water is salt or even sea water. Since consumer demands equal, or nearly equal demineralization, the three processes most closely studied are ion exchange, solar distillation and electrodialysis.

Ion exchange, which is suitable for obtaining pure water from slightly salty water, is used with particular success by small mobile groups in the Sahara, where the limited demands it makes on transport, its simplicity of operation and safety represent considerable advantages. The resins are kept in small plastic containers, and regeneration operations are centralized at one point.

Very interesting practical results have been obtained with small portable prefabricated solar stills, and many are in service to supply water for drinking, medical and pharmaceutical needs, and for technical uses. A detailed study of local needs and related problems has enabled this process to be of practical value.

However, all costs remain well above the desired level, and further research must be carried out to improve existing processes or to find other solutions, such as, for example, the partial softening of water. Drainage water from irrigation becomes concentrated by evaporation, and this water could be used as regeneration brine for ion exchange which in turn could be used to soften water to the concentration used for irrigation. Very hard saline water could also be concentrated, and by a similar process the softened water could be used for drinking purposes; it has yet to be determined, however, whether this water would be medically acceptable.

A method of culture proposed by Messrs. Trombe and Foex consists of a sort of greenhouse in the middle of

which brine is evaporated by means of the solar energy falling on the greenhouse. The condensed water falls to the bottom of the greenhouse, which is shaded by the brine troughs, and there cultivation takes place in a humid warm atmosphere. It would appear that this process could be economically possible for market gardening.

The author considers that the two best lines of research are, on the one hand, a deeper study of plant, animal and human metabolism, and, on the other hand, the invention of devices for stopping the considerable waste of energy in arid zones caused by the evaporation of water used in very dry atmospheres.

DISCUSSION

D. Denton. Have you any observations on the effects on humans or animals of water with high Mg^{++} or Ca^{++} content? You mentioned that in some areas with which you are concerned humans drink 10–15 l. of water per day. Is this due mainly to loss by sweating, and if so would it not be an advantage if the water contained a considerable amount of NaCl to replace the loss in sweat? In communities in these areas, this may be beneficial for the whole population, with the exception of those under treatment for heart disease or hypertension.

C. Gomella. A tort ou à raison, les sels de calcium sont considérés au Sahara comme moins physiologiquement actifs que l'ion magnésium et que l'ion sodium associé à l'ion sulfate. Cependant, c'est là une question de physiologie qui mérite d'être étudiée de très près par des chercheurs spécialisés compétents.

Les 10 à 11 litres cités par moi transitent bien à travers le corps et sont principalement évacués par les pores de la peau et, pour une moindre part, par les autres voies de sécrétion.

Sous réserve du résultat des recherches que je viens juste de mentionner, il apparaît bien que le maintien d'une certaine quantité d'ions dans l'eau de boisson est tout à fait utile. Mais la quantité exacte n'a pas été déterminée scientifiquement. Nous avons là un exemple de l'inadaptation aux zones arides des normes des zones tempérées.

J. H. Whitney. Have you any idea of the procedure which might be used to determine how much we might alter temperate zone standards for potable waters? Might we study the salt requirements of persons using waters more brackish than permitted by existing standards?

C. Gomella. L'étude de cette question relève de la physiologie humaine et de la médecine au sens le plus général. Le traiteur d'eau que je suis est incompétent en la matière, il ne peut en principe que s'incliner devant les exigences des organismes officiels fixant les normes. Cependant j'ai le sentiment très net que les normes des pays tempérés sont inadaptées aux zones arides chaudes. Je suis également persuadé que, si une modification des normes actuelles intervenait, elle se ferait dans un sens qui faciliterait le travail du traiteur d'eau, c'est-à-dire qu'on assisterait à un relèvement général de la valeur admise pour les taux minimums de minéralisation tolérés.

En France, il existe au moins un organisme, Prohuza, qui s'occupe activement de recherches portant sur des points tels que: le bilan hydrominéral chez les travailleurs sahariens; les effets de la surhydratation; la définition nouvelle de la potabilité des eaux en zone aride.

E. D. Howe. Can the waters of the Sahara, which are rich in $CaSO_4$, be partially purified by "heat treatment"? In other words, can any substantial reduction in total dissolved salts be accomplished by taking advantage of the reduced solubility of this salt with increases in temperature?

C. Gomella. L'idée que vous avancez n'a pas fait l'objet d'études spéciales. Cependant cette voie ne sera peut-être pas très fructueuse en raison de la forte teneur en chlorure de sodium des eaux contenant le sulfate de calcium. La solubilité de ce sel se trouve ainsi augmentée et l'effet de la température sur la diminution de solubilité du sulfate de calcium est diminué.

FRESH WATER FROM SEA WATER BY MULTIPLE EFFECT EVAPORATION

by
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The subject matter of this paper, at least in principle, is quite old. Multiple effect evaporators have been used in industry for more than 100 years and have been used for sea water distillation for about 60 years. The development of sea water evaporators, however, has followed an entirely different course from the development of evaporators for industrial use. This is because sea water evaporators were originally built for shipboard use, where the main requirements were for compactness, ease of operation, and the utmost reliability. The most important characteristics of sea water are its corrosiveness and its tendency to deposit an insulating layer of scale on all heating surfaces. Thus, it was also necessary that sea water evaporators be built of expensive alloys and arranged in such a manner that they could be de-scaled easily.

In large, land-based, industrial evaporator plants, the requirements are much less stringent. Our work for the Office of Saline Water of the United States Department of the Interior has been to apply industrial evaporation techniques to the distillation of sea water. In a preliminary phase, flowsheets or plant arrangements were developed that showed promise of producing distilled water far more cheaply than heretofore believed possible. This was accomplished primarily by using the cheapest type of evaporator available today in flowsheets that were much more complex than usually considered practical. It was found that single-unit plants having capacities of the order of 15 million gallons a day could be built from equipment that is already available and well proven.

The type of multiple effect evaporator flowsheet developed for the Office of Saline Water is shown schematically in the lower right-hand section of fig. 1. This is a conventional backward feed evaporator except that much more attention than normal has been directed toward recovery of heat at the highest possible temperature levels. Cold sea water enters at the right and first passes through a heat exchanger where it condenses the vapour given off in the last or coldest effect of the evaporator. This sea water is heated further, partially by hot distilled water and partially by hot waste brine. It then enters the last effect where some pure water vapour is driven off by condensation of pure water vapour from the next effect. The partially concentrated sea water is pumped out of the last effect through two more heat exchangers to the next effect and is finally discarded as strong brine from the first or hottest effect. The heat in this waste brine is recovered in one set of heat exchangers and the heat in the hot distilled water in the other set of exchangers.

The steam used by this multiple effect evaporator might be at any pressure from less than atmospheric to possibly 5 atm. absolute. The source of the steam is not critical, but it is most likely that it would come from a fuel-fired boiler or a nuclear reactor. It usually costs little more to generate the steam at a higher pressure than needed by the evaporator and to expand it through a turbine first. This turbine can be used to generate electrical power for sale. The power-producing part of the plant is then very similar to a conventional fuel-fired power plant, as illustrated at the top of fig. 1. The only difference is that the last stages of the turbine are eliminated when the steam is to be used in the evaporator.

The flow diagram of fig. 1 shows only three effects in the evaporator, whereas an actual plant would be more likely to have 10 or more effects. The number of effects used would, of course, depend on the value of the steam and the relative amounts of power and water needed. A more complete flow diagram for a typical plant is shown in fig. 2. The top part of the flow diagram follows conventional power plant practice, but could be replaced in its entirety by a nuclear reactor cooled by boiling water. The bottom part of fig. 2 shows a 12-effect evaporator capable of producing about 10.5 lb. of distilled water per lb. of steam used. The extra fuel oil requirement, in excess of what would normally be needed to produce the power alone, is only about 1.9 gallons per 1,000 gallons of distilled water.

If a plant were needed to produce distilled water but there was no market for the power, the electric generator

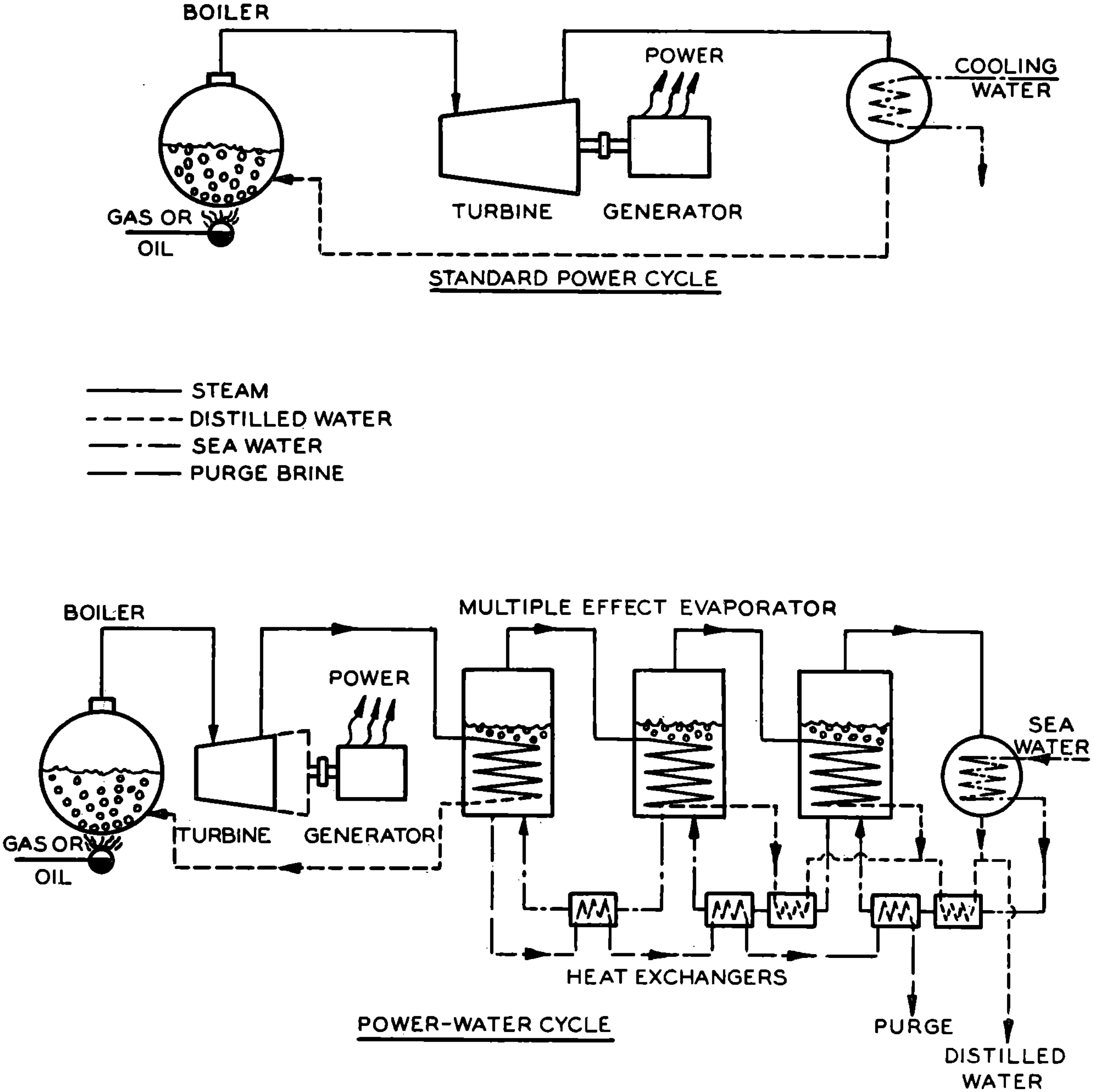

Fig. 1. Comparison of standard power cycle with proposed cycle.

of figs. 1 and 2 could be replaced by a vapour compressor. This compressor would be part of a thermocompression evaporator as shown in fig. 3. Vapour would be taken from the highest temperature effect (where the volume to be handled is smallest) and would be compressed to serve as the heating medium in the same effect. The flows of sea water, distilled water and waste brine would be much the same as in the plant producing both power and water. A more detailed flow diagram of this type of plant is shown in fig. 4. Steam generated in the boiler at top right is expanded through two turbines, one to produce the power needed by pumps, etc., in the plant (and some for sale, if desired), and one to drive the vapour compressor. The thermocompression evaporator would be split up into several bodies, connected in series with respect to sea water flow. This is done partially because of size limitations but mainly to confine the strongest, highest boiling, sea water in only one or two bodies. The thermocompression evaporator is heated by vapour from the compressor and exhaust steam from the turbines. This produces more distillate vapour than needed by the compressor and the excess is bled off to heat the 10-effect

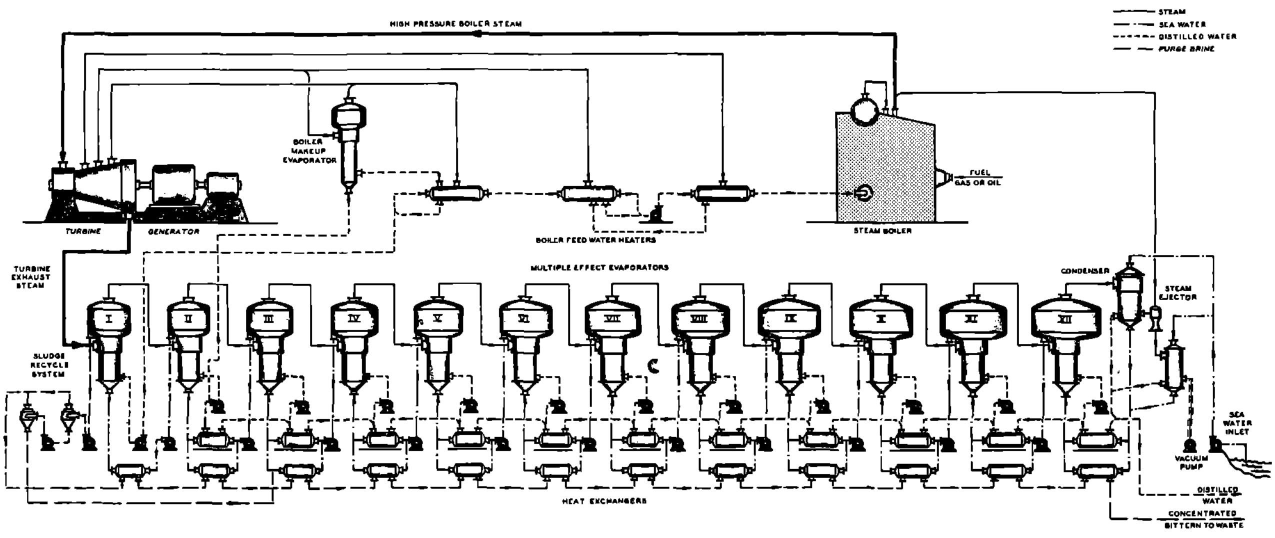

FIG. 2. Flowsheet of sea water distillation plant.

evaporator shown along the bottom of fig. 4. This cycle is able to produce as much as 20.8 lb. of distilled water per lb. of steam generated in the boiler, or 280 gallons of distillate per gallon of residual oil burned in the boiler.

The type of evaporator proposed for use in these flowsheets is the long tube vertical or Kestner evaporator illustrated in fig. 5. This type has never before been used for sea water distillation, partly because it has such long tubes (15–35 ft.) that de-scaling is difficult, and partly because the evaporator is so tall (20–60 ft.) that it cannot be installed aboard ship. Nevertheless, in large sizes, this type of evaporator is by far the cheapest per unit of heating surface or per unit of distillation capacity. It can be built in large sizes, primarily because the tubes are long and closely packed so as to permit easy shipment of the heating element. The top vapour head is a simple cylindrical chamber that can be fabricated in the field.

The long tube vertical evaporator can be designed to operate rising or falling film, depending on which arrangement gives the highest heat transfer rates. In the rising film version shown in fig. 5, feed sea water enters at the bottom of the tubes and is concentrated in a single pass up through the tubes. The evolution of vapour as the liquor rises causes a large increase in volume which imparts a high velocity to the vapour-liquid mixture. As a result, heat transfer coefficients are quite favourable. The vapour-liquid mixture issuing from the tops of the tubes is separated in the vapour chamber and the unevaporated liquid is drawn off to the next effect as fast as it accumulates. There is no liquid level to control and the residence time of sea water in the evaporator is of the order of only a few seconds.

In the past, the scaling tendencies of sea water have been combated mainly by designing the evaporator for easy scale removal. This has resulted in the use of evaporators far more costly than would otherwise be necessary. More economical results can be achieved if scale can be prevented from forming in the first place. The flowsheets and type of evaporator we have proposed are practical only if an economical means of scale prevention is used. It is only in the last few years that such means of scale prevention have been developed. Perhaps the simplest is the control of the acidity or *p*H of the sea water. The two most important and troublesome scale formers are calcium carbonate and magnesium hydroxide. It is now well accepted that these can be kept in solution by the addition of an acidic material to the evaporator. Materials used for this purpose range from citric acid to ferric chloride. In a large land-based plant where close control can be exercised, there is no reason why the cheapest and strongest of the inorganic acids should not be used. In most cases, this would be sulphuric acid and the cost of the acid would usually not exceed $0.02 or $0.03 per 1,000 gallons of distilled water.

The principal objection to the use of acid for scale prevention is that it increases the corrosiveness of the sea water. Pilot plant tests for the Office of Saline Water indicate that the increase is not serious. Nevertheless, until appreciably more experience has been gained on the pilot plant or demonstration plant scale, it would be unwise to build such plants of any material less corrosion-resistant than admiralty metal or aluminium brass. The use of such alloys increases the cost of the evaporator to a little more than 50 per cent above the estimates given later in this paper. However, since the cost of the evaporator is less than half the total plant cost and since capital charges on the plant are only half the operating cost, the increase in water cost is less than 15 per cent. Thus, sea water evaporation plants of the type just described can be built now, of proven materials and equipment, to produce distilled water from sea water at costs less than $0.50 per 1,000 gallons. This estimate is based on the assumption that the plant would be built at a cost equivalent to that at which it could be built in the United

States, that it would be designed to produce more than 10 million gallons of water per day, that fuel would cost no more than $0.30 per million BTU, and that capital and maintenance charges did not exceed about 11.5 per cent of plant cost per year.

Original estimates of plant and water cost made for the Office of Saline Water were based on the assumption that the method used for scale prevention would add very little to the cost of the distilled water and would reduce the corrosive tendencies of sea water to the point where mild steel, the cheapest possible material of construction, could be used. A promising method proposed by the authors is now undergoing pilot plant tests for the Office of Saline Water. In this method, solid particles of the scale-forming ingredients are suspended in the evaporating sea water. The intention is that further precipitation would be on these particles, in preference to precipitation on the heating surface. Since the major scaling ingredients are alkaline, it is possible to keep the sea water alkaline so that corrosion should be much less severe. Furthermore, by separating the solids from the concentrated sea water before it is discarded, and returning these solids to the evaporator, there would be no need for a continual replenishment of the solids. Losses should be replaced by further deposition of the scaling ingredients entering with the raw sea water.

The pilot plant work on this method of scale prevention is now in progress. Preliminary results are promising, but operation has not been of sufficiently long duration to prove the practicality of the process or the effect on mild steel as a material of construction.

The pilot plant work now being conducted by the authors for the Office of Saline Water has four objectives. Most important of these is the development of this "sludge re-circulation" method of scale prevention. Another is to determine the heat transfer performance of the long tube vertical evaporator under the conditions that would be encountered in the flowsheets of figs. 2 and 4. Another is the determination of the minimum acidity needed when acid is used to prevent scale formation. The fourth objective is an evaluation of various possible materials of construction.

The test evaporator, which is located at Wrightsville Beach, North Carolina, has seven tubes, each of a different metal, but all of the same dimensions as would probably be used in a full-scale plant. The tubes are insulated from each other and from the steel shell to prevent galvanic corrosion. Since the feed to one effect of a complete plant would be the product of another effect, it was necessary to install several feed preparation evaporators at this test facility. These are of the forced circulation type, which are less susceptible to scale formation. They could better be relied on not to remove all the scale ingredients from the sea water before it reached the test evaporator. The pilot plant has been in operation for almost a year but work to date has been exploratory and no runs have been for more than a week. In the near future, runs of 1,000 hours' duration will be made to prove out the operating conditions that appear most practical. A reasonable evaluation of the various materials of construction cannot be made until these long runs are completed.

In the preliminary work for the Office of Saline Water, estimates were made of the minimum cost of water that might ultimately be expected if all reasonably hopeful assumptions were fulfilled. These assumptions were that mild steel could be used as the only material of construction, that the long tube vertical evaporator could be kept free of scale at little cost, and that heat transfer performance would be reasonably high. The first of these assumptions has not yet been proven, the second has been brought to the point where cost is of the order of $0.02

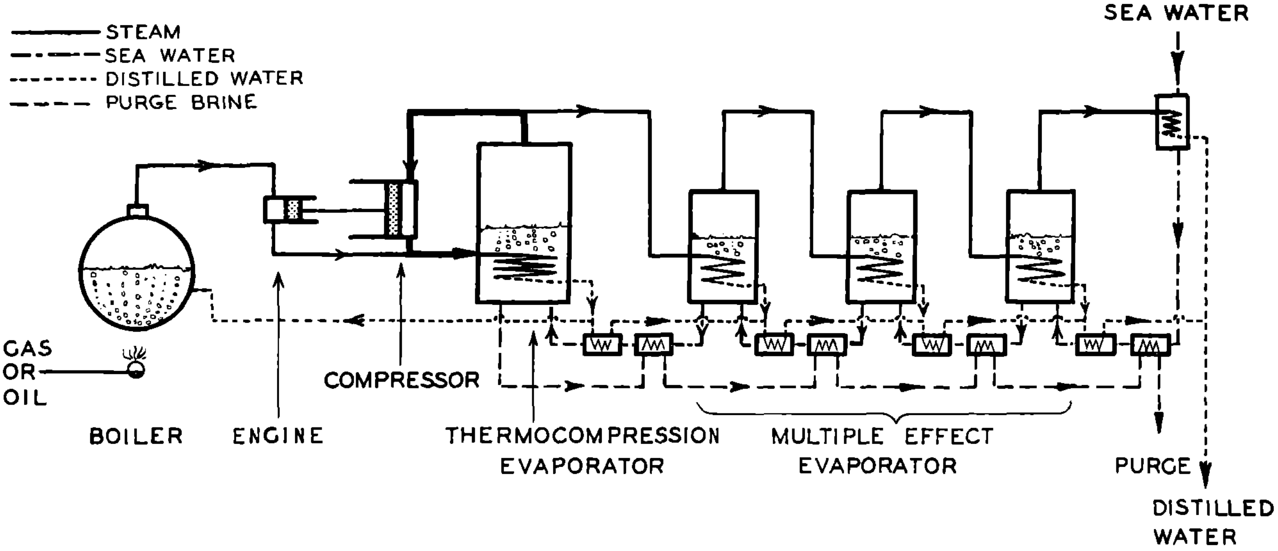

FIG. 3. Functional flow diagram of process.

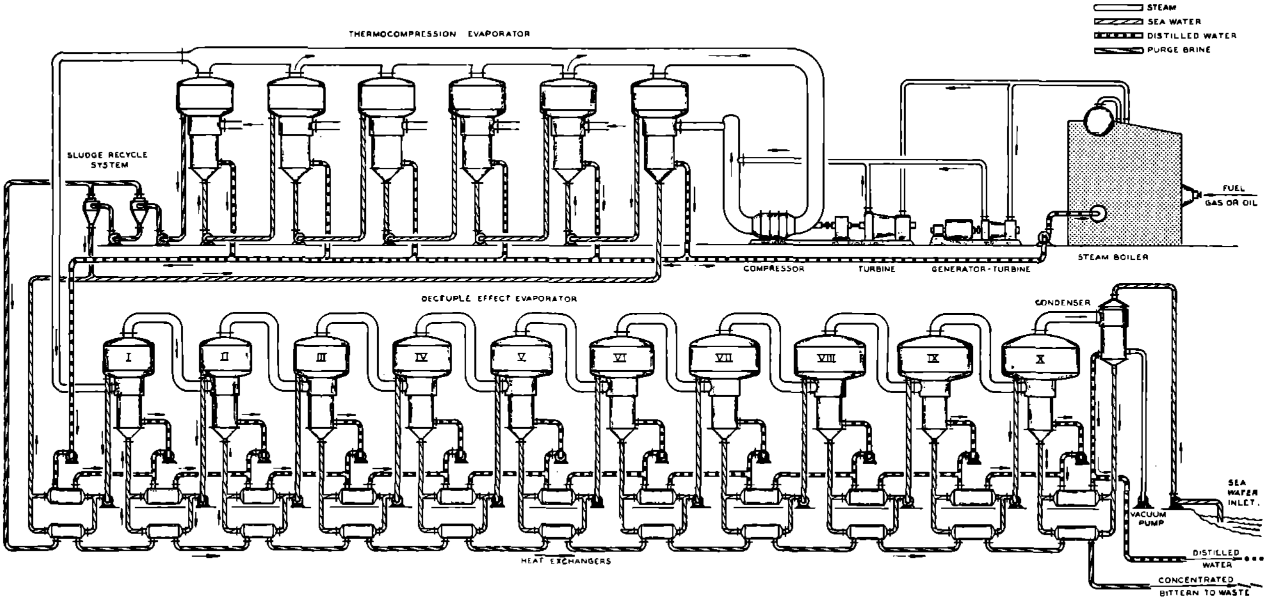

FIG. 4. Flowsheet of sea water distillation plant.

or $0.03 a thousand gallons, and heat transfer data accumulated so far indicate that the original estimates were not overly optimistic. The original cost estimates were made in 1955 and were presented at the symposium on Saline Water Conversion held in Washington in 1957.

In view of the general rise in prices since 1955 and changes in fuel costs, the original estimates should be revised. However, such revision means that the plant conditions originally selected might no longer be the most economical. Therefore, the estimates are repeated in Tables 1 to 4 in their original form. Adjustments can be made for local conditions, but if the changes are large, it will probably mean that the plant is no longer the optimum design. For instance, if the unit price of fuel were twice that shown, it would be desirable to add more effects, thereby increasing the efficiency and first cost of the plant, in a further effort to reduce fuel cost. General factors that can be applied to these estimates are as follows: (a) a 13 per cent increase in first cost to reflect inflationary trends since 1955; (b) a 15 per cent increase in first cost for extra design, transportation, and contingency allowances for the first plants built at locations remote from equipment suppliers; (c) a 50 per cent increase in evaporator and heat exchanger cost if the plant must be built of copper alloys instead of mild steel; (d) adjustments in overhead, labour, and fuel rates in proportion to those given to reflect local conditions.

The cost estimate of Table 1 shows total capital cost of the multiple effect evaporator of fig. 2. This estimate is based on an 18,170 acre-foot-per-year 12-effect evaporator heated by atmospheric pressure steam from a 60,000 kW power plant. The capital cost of the power-producing section of the plant, which is not included in Table 1, would be about $6,400,000.

TABLE 1. Capital cost of an 18,170 acre-foot-per-year 12-effect evaporation plant using 212° F. exhaust steam from 60 MW power plant

	Cost in dollars
Evaporators (2 sets)	3 695 000 installed
Heat exchangers	455 000 installed
Condensers and auxiliaries	300 000 installed
Pumps	136 000 installed
Piping	214 000 installed
Instruments	35 000 installed
Total installed process equipment	4 835 000
Site development	40 000
Additions to power plant service facilities	65 000
Weatherproofing	240 000
Engineering	385 000
Contingencies	485 000
Total plant cost or $322 per annual acre-foot	6 050 000

The operating cost of this evaporator plant is shown in Table 2. The costs of steam and power were arrived at by assuming that all power produced by the plant would be sold at the cost of making it in a conventional steam power plant of the same size. The cost of the atmospheric pressure steam was then equal to the extra cost of building and operating the plant to exhaust steam from the turbine at atmospheric pressure instead of at high vacuum. The costs of steam and power to the evaporator plant were based on a fuel cost of $0.30 per million BTU and can be adjusted upward to correct for higher fuel costs. However, since about one-third of the steam cost

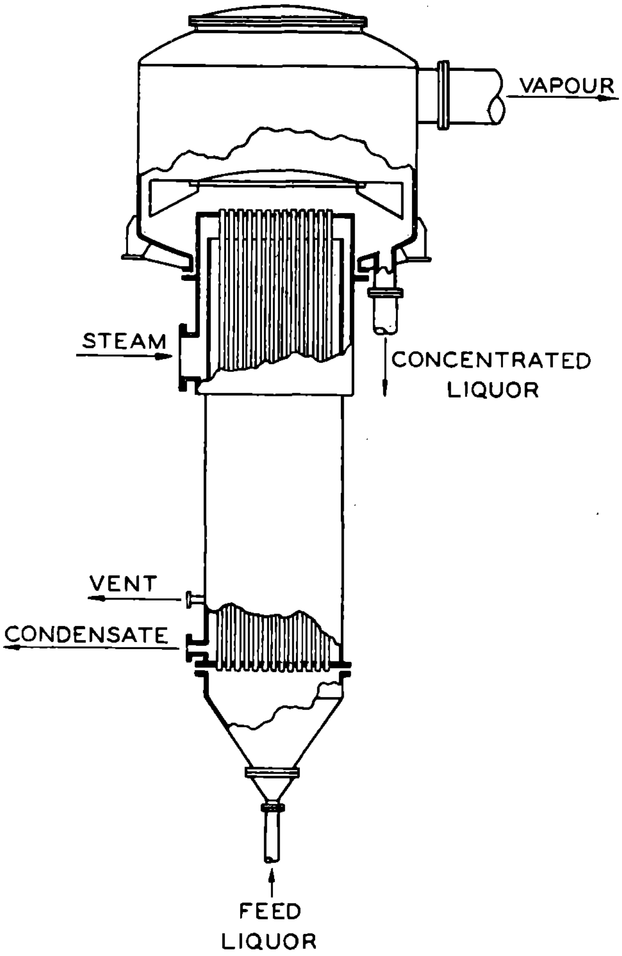

FIG. 5. Long tube vertical evaporator.

is capital charges on the power plant, adjustments for lower fuel prices should not be attempted. If all the percentage increases mentioned in (a), (b) and (c) above are applied, plant first cost of Table 1 would increase to $10,600,000. If fuel price were also increased to $0.40 per million BTU, total distilled water cost of Table 2 would increase to about $116 an acre-foot or $0.36 a thousand gallons. To this should be added about $0.03 a thousand gallons to allow for the acid currently needed for scale prevention. These figures represent prices that can be achieved on the basis of existing knowledge and proven techniques.

The original capital cost estimate for the combination multiple effect thermocompression evaporator of fig. 4 is shown in Table 3. Since distilled water is the only product, all costs are shown, including the boiler and turbines. Costs of the major items of equipment were obtained in 1955 from manufacturers who had built such equipment in approximately the sizes needed. The boiler would be a moderate size power plant type for which the Foster Wheeler Corporation furnished price information. The Allis Chalmers Corporation have built turbines and

TABLE 2. Annual operating cost of an 18,170 acre-foot-per-year 12-effect evaporation plant using 212° F. exhaust steam from 60 MW power plant

	Cost in dollars
Interest: 3 % of total capital	182 000
Insurance: 1 % of total capital	60 000
Depreciation: 5 % of total capital	303 000
Maintenance: 3 % of equipment cost	145 000
Labour: $2.50 per man-hour	86 000
Power: 5.16 mills per kWh	54 000
Steam: $0.1218 per million BTU	554 000
Total	1 384 000
or $75.90 per acre-foot	
or $0.233 per 1,000 gallons	

TABLE 3. Capital cost of an 18,650 acre-foot-per-year combination thermocompression and 10-effect sea water evaporation plant

	Cost in dollars
Boiler	1 020 000 installed
Turbine: generator	170 000 installed
Turbine: vapour compressor	925 000 installed
Evaporators	2 425 000 installed
Heat exchangers	991 000 installed
Pumps	138 000 installed
Piping	305 000 installed
Instruments	40 000 installed
Total installed process equipment	6 014 000
Site development	70 000
Office, shop and laboratory	135 000
Weatherproofing	300 000
Engineering	481 000
Contingencies	600 000
Total plant cost	7 600 000
or $407.50 per annual acre-foot	

TABLE 4. Annual operating cost of an 18,650 acre-foot-per-year combination thermocompression and 10-effect sea water evaporation plant

	Cost in dollars
Interest: 3 % of total capital	228 000
Insurance: 1 % of total capital	76 000
Depreciation: 5 % of total capital	380 000
Maintenance: 3 % of equipment cost	180 000
Labour: $2.50 per man-hour	138 000
Fuel: $0.30 per million BTU	991 000
Total	1 993 000
or $106.90 per acre-foot	
or $0.328 per 1,000 gallons	

compressors in the sizes needed and supplied cost and performance data. The only equipment not previously built in the required sizes was the evaporator itself. The Swenson Evaporator Company, Division of the Whiting Corporation, have built evaporator bodies of this type in sizes one-third as large as needed for this plant and they supplied cost estimates for the larger evaporators. If the capital costs of Table 3 were increased by the percentages given previously, the cost, at the time of writing, of an 18,650 acre-foot-per-year plant of this type would be about $12,100,000. If fuel cost increased also to $0.40 per million BTU and $0.03 a thousand gallons were added for acid treatment, the maximum cost of distilled water would be $0.50 a thousand gallons or $163 an acre-foot. This represents water prices that can be achieved on the basis of only existing knowledge.

While the above figures are appreciably lower than results currently achieved in existing plants, there is still considerable room for improvement. The most promising improvement in the application of these cycles will be through the use of cheaper and less destructive means of scale prevention. It is hoped that this will make possible the construction of such plants out of the cheapest of materials—ordinary low carbon steel. Continuation work on heat transfer characteristics of these evaporators may point the way to further economies. This work is being actively pursued under the sponsorship of the Office of Saline Water. The present pilot plant programme has already progressed far enough to permit design of a larger plant. The next step will be an experimental demonstration plant utilizing the combination thermocompression-multiple-effect cycle of fig. 4 and having a capacity of approximately 1 million gallons of distilled water a day.

RÉSUMÉ

Production d'eau douce à partir de l'eau de mer au moyen d'évaporateurs à plusieurs étages (W. L. Badger et F. C. Standiford)

Tous les travaux décrits ci-après, aussi bien les calculs que les expériences, ont été effectués sous les auspices de l'*Office of Saline Water* du Département de l'intérieur des États-Unis aux termes d'un contrat passé avec cet organisme.

Les calculs ont porté sur l'emploi d'un évaporateur vertical à long tube, permettant d'assurer l'évaporation fractionnée de l'eau de mer. Deux types fondamentaux d'écoulement laminaire ont été étudiés. Dans le premier système, la vapeur, qui arrive à une pression modérée (de 55 à 60 atmosphères), se détend dans une turbine, d'où elle s'échappe à une pression légèrement supérieure à la pression atmosphérique. L'énergie produite par cette turbine entraîne un compresseur qui envoie la vapeur dans un évaporateur à thermocompression. L'échappement de la turbine sert à chauffer un évaporateur à plusieurs étages. L'évaporateur à thermocompression peut comprendre un ou plusieurs corps. L'installation ainsi constituée donne un seul produit susceptible d'être vendu, qui est de l'eau.

Dans le deuxième système, les turbines d'une centrale de type normal sont modifiées pour fonctionner sous une contre-pression à peu près égale à la pression atmosphérique. L'échappement réchauffe un évaporateur à plusieurs étages. Cette installation produit à la fois de l'eau et du courant électrique.

Si l'on a choisi un évaporateur vertical à long tube pour les calculs ci-dessus, c'est parce que ce modèle est le moins coûteux à réaliser. D'une façon générale, on ne considère pas qu'il soit utilisable lorsqu'on emploie de l'eau qui laisse un dépôt calcaire. C'est pourquoi il est apparu nécessaire de construire une installation pilote afin d'étudier des méthodes permettant d'empêcher l'entartrage.

Deux méthodes de ce genre ont été étudiées. La première consistait à contrôler attentivement le *p*H de l'eau. Elle a parfaitement réussi, bien qu'on n'ait pu déterminer avec assez de précision les valeurs minimums du *p*H nécessaires pour prévenir tout entartrage.

La deuxième méthode consistait à renvoyer en circuit dans l'appareil une boue ayant à peu près la même composition que le tartre dont on pouvait prévoir la formation. Dans ce cas aussi, le succès a été complet, l'appareil ayant fonctionné jusqu'à neuf jours sans interruption. On envisage pour l'avenir immédiat des essais de plus longue durée. En conséquence, l'emploi d'un évaporateur vertical à long tube est pleinement justifié.

En fondant les calculs sur les conditions courantes aux États-Unis (amortissement étalé sur vingt ans et emploi d'un combustible coûtant 30 cents par million de BTU[1]) le devis d'une installation conçue selon le premier système est le suivant:

Capacité de l'installation d'eau douce par 24 heures	Frais de premier établissement de l'installation complète	Prix de revient de l'eau douce[2] par millier de gallons
gallons[1]	$	$
1 300 000	1 400 000	0,80
17 000 000	8 700 000	0,36

[1] Un gallon des États-Unis vaut 3,8 litres environ.
[2] Y compris les frais fixes et les frais de fonctionnement.

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[1] Un BTU vaut 0,25 grande calorie.

Dans le cas des installations fonctionnant selon le deuxième système, les frais correspondants sont plus difficiles à calculer, en raison du nombre des variantes possibles, ainsi que de la nécessité de savoir s'il faut construire une centrale électrique neuve ou s'il est possible d'aménager une centrale ancienne. De même, dans ce deuxième cas, le facteur "recettes provenant de la vente de courant" est très important, et ce prix de vente varie selon le lieu. En partant de données moyennes, on obtient les chiffres ci-contre (dans le cas où l'on doit simplement transformer une centrale existante):

Capacité de l'installation d'eau douce par 24 heures	Premiers frais pour les transformations et l'équipement neuf	Prix de revient de l'eau douce par millier de gallons[2]
gallons[1]	$	$
1 300 000	750 000	0,30
17 000 000	7 000 000	0,25

[1] Un gallon des États-Unis vaut 3,8 litres environ.

[2] L'électricité est vendue au prix de 0,004 dollar le kWh. Si l'électricité pouvait être vendue au prix de 0,007 dollar le kWh, le prix de revient de l'eau serait nul.

THE ELECTRODIALYTIC DESALTING METHOD DEVELOPED BY THE CENTRAL TECHNICAL INSTITUTE (TNO)[1] IN THE NETHERLANDS AND BY CO-OPERATING COUNTRIES

by

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INTRODUCTION

In the difficult conditions obtaining in Holland in the last years of the war, TNO was actively engaged in turning to account the small volume and variety of raw materials available. One of the problems studied was the preparation of low-salt pepsin from a saline liquid. The electrodialysing process was the method adopted for this purpose. Once the war was over there was no further interest in this particular problem.

In the post-war years there was a large surplus of another saline protein solution suitable for desalting, namely whey, which is the surplus remaining from milk in cheese manufacture. The problems of desalting this product were solved.

Figure 1 shows a diagram of the electrodialysing unit that was used. The membranes (cellophane) act as filters through which the ions are drawn as a result of the voltage difference, but through which the much bigger protein molecules cannot pass.

At the time these investigations were completed, it was decided to try to convert brackish water into drinking water by electrodialysis. From the purely technical point of view there was no problem. What had been possible with a difficult liquid like whey, which contains lactose and proteins, was bound to be possible with brackish water. However, there was one very big difference. In processing whey, the product recovered was comparatively costly—drinking water, on the contrary, had to be very cheap for reasons of public hygiene and, of course, because a high price would encourage other processing methods.

These cost considerations made it necessary to develop another method, very different from the first one.

The removal of salt from the liquid in the middle compartment (fig. 1) is proportional to the amperage. But the voltage needed to reach this amperage also governs power consumption. In a three-cell unit this voltage is fairly high owing to the voltage loss at the electrodes and that needed to overcome the resistance of the then fairly wide liquid layers and of the membranes.

Matters are greatly improved if the required voltage can be lowered.

The adverse effect of the voltage loss at the electrodes can be reduced by using one pair of electrodes for many compartments. This is possible with selective membranes, namely, membranes which are themselves electrically charged, positive membranes only allowing negative ions to pass and vice versa (fig. 2).

Figure 2 clearly shows that the principle is the alternation of desalting and concentrating compartments.

In principle, it is obvious that an infinite number of such compartments could be placed between the electrodes. The voltage loss at the electrodes and in the electrode cells is thus spread over so many demineralizing compartments that this part of the power consumption is very small.

A second way of favourably affecting power consumption is by making the compartments as thin as possible. This reduces electrical resistance and hence the voltage required per compartment. Reducing the compartment width to 1 mm. requires a special construction, as inlet and outlet conduits must be provided, within the slight available width of 1 mm., for both circuits, i.e., for the demineralizing compartments and for the concentrating compartments. A special construction was chosen, whereby the inlet and outlet conduits are located in the membranes.

Thirdly, the membrane resistance greatly influences total power consumption. Hence there has been a constant endeavour to manufacture membranes having the required electrical charge together with low electrical resistance.

Finally, polarization can be expected at the membrane surface. The laminar liquid layer flowing along the membrane will be most strongly desalted. This causes an

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[1] The initials TNO stand for the Dutch National Council for Applied Scientific Research, which was created by an Act of 30 October 1930. It is partly State-supported, but works partly on sponsored projects. The organization's Central Technical Institute and Central Laboratory have been especially concerned in this work, the former developing the apparatus and assisting the Central Laboratory in membrane development.

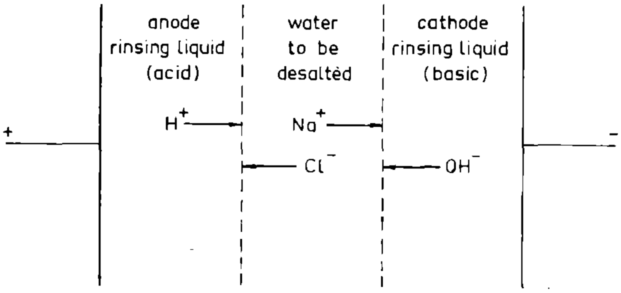

FIG. 1. Diagram of 3-compartment electrodialysing unit.

undesirable increase in resistance. Development work has thus aimed at providing frames between the membranes and ensuring a liquid velocity such that the greatest possible turbulent flow is promoted.

TNO had made considerable progress on these lines when the discussions on demineralizing brackish water and sea water were started by Working Party 8 of the Organization for European Economic Co-operation (OEEC). Not only did the OEEC countries take part, but also the British Commonwealth countries and America—the latter by special invitation.

As far as was possible in 1952–53 the working party discussed the cost of the various demineralizing methods. Although great difficulty was experienced in reducing to a single costing method the data originating from the various sources, a clear picture was nevertheless obtained. Briefly, this showed that the cheapest method of demineralizing water with a salt content of about 35,000 ppm. tds. (sea water) or more was by distillation. Water with approximately 500 ppm. tds. and requiring further purification can best be processed with ion-exchange materials. For water with salt contents between these limits electrodialysing appeared to be indicated.

This expectation led a number of interested countries to continue TNO's research for their joint account, while one of these countries also employed its own resources in a study based on the same principles, of a very important and sharply defined problem of its own.

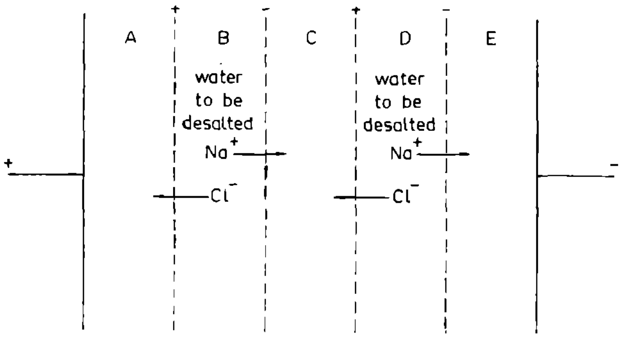

FIG. 2. Diagram of multi-compartment electrodialysing unit with selective membranes.

At the time this collaboration began, membranes with an area of 60 × 20 cm. were being used. One of the essential developments was to change over to bigger dimensions. In order to ensure that this was done adequately, the capital outlay was estimated according to the size and number of membranes per unit. (See Tables 1 and 2.)

TABLE 1. Price variation of the water produced resulting from increasing membrane size

Membrane size	Price
cm.	%
60 × 20	100
150 × 40	41
300 × 40	35
300 × 90	29

TABLE 2. Price variation of the water produced resulting from increasing the number of membranes per unit

Number of membranes	Price
	%
200	100
400	75
800	62

It will be seen from these tables that a very substantial improvement can already be attained with membranes measuring 150 × 40 cm. and numbering 800 per unit. Increasing the number of membranes per unit and enlarging their dimensions does indeed reduce the price per cu.m. water; however, it seemed unwise to make the increase too big in the first instance.

This view was based not only on considerations of research policy, but also on technical grounds. The weight of the unit increases with the number and size of the membranes, and becomes less easy to handle. This was a disadvantage since it was planned to make the unit transportable. Furthermore, the required voltage increases with the number of membranes, and for reasons of safety we preferred to limit it to several hundred volts per stack.

The development work resulted in the use of a 100 × 40 cm. unit following that of 150 × 40 cm., in order to make handling still easier and to allow the membranes to be fitted by one man. In South Africa, however, where units had to be built for a very definite purpose and where transportability was not a main factor, the number of membranes has been further increased to 2,000 and their size to 70 × 225 cm.

Before the unit is described in greater detail, it should be mentioned that the countries collaborating in this research project have come to the conclusion that construction of the unit must in principle disregard the membrane quality, thus leaving producers and users free to choose the membranes best suited to their technical requirements and financial resources. Active research was carried out in order to obtain good, cheap membranes which could be supplied in any desired size. It was doubtful whether the work carried out by private enterprises and research institutes would yield results in time. As things turned out it did, and in various ways and in various places membranes are being produced by the reel. Moreover, it has become clear that these membranes have years of useful life, provided the electrodialysing process is adequately controlled.

THE DESALTING UNITS

A desalting unit and the method now adopted may be characterized by six main features, viz.:

1. Feeding conduits across the membranes.
2. Separators supporting the membranes at a great many points scattered all over the membranes.
3. Subdivision of the total membrane stack, by means of rigid intermediate frames, into separately removable smaller stacks.
4. A membrane size of 40 × 100 cm., 40 × 150 cm. or 70 × 225 cm.
5. Non-laminar flow conditions.
6. Upward flow direction in all the compartments, with a small angle between the directions in alternate compartments.

The above features, in addition to what was stated in the introduction, may now be considered in detail.

1. As already stated, the compartments should be as thin as possible. The limiting factor in this respect appears to be mainly the necessity to have liquid supply and withdrawal conduits to and from each compartment. Such conduits will usually be present in the form of small holes within the gaskets actually forming the walls of the compartments, these holes connecting the compartments with some main conduits running across or even outside the gaskets.

   In order to avoid this limiting factor the position of the main conduits was shifted into the actual compartments by providing all the membranes with four corresponding holes yielding four main conduits across the membrane stack. By joining the borders of the holes of every alternate pair of membranes watertight and in an appropriate order, the necessary connexions with the various compartments are obtained. The necessary joints can be made without any glue by introducing an appropriate pressing organ, or similar gadget, between each pair of membranes (fig. 3).
2. The flexible membranes are held apart by thin separators which should give the support required without blocking either the passage of electric current or the flow of the liquids. Corrugated, perforated and rigid pvc.-sheets as well as pvc.-sheets modelled into a kind of gauze by means of the expanded metal technique seemed to provide excellent separators.

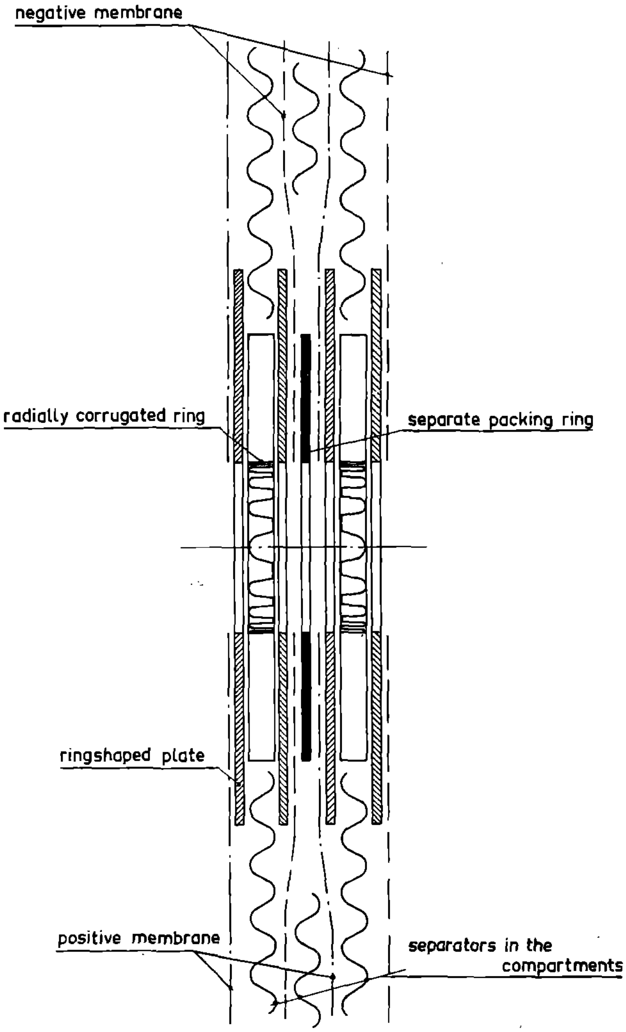

FIG. 3. Cross-section through two supply membranes and corresponding membranes.

By means of the techniques mentioned above under (1) and (2), compartments with a thickness of 1 mm. have been made, the value of which appears to be fairly near the estimated optimal thickness with respect to the necessary balance between the pumping energy and the direct current energy consumption.

3. The unit comprises from 2 × 400 to 2 × 1,000 membranes. The total membrane stack, however, is divided into sub-divisional stacks—generally of 2 × 50 membranes each—by means of rigid intermediate frames which bound the stacks and provide external inlets and outlets for the two liquids (concentrate and diluate).

   The subdivisions serve three different purposes: (a) To obtain a smaller diameter of the main conduits (and hence a smaller loss of profitable membrane area) without causing unequal distribution of the feed liquid among the compartments. (b) They prevent bending and deformation of the total membrane stack. (c) They make possible the separate removal and replacement of ready-made sub-divisional stacks; this lowers the cost by the failure of any individual membrane.

A picture of one such sub-divisional membrane stack, including the intermediate frames, is given in Plate XVIII.

4. Various comparatively large membrane sizes, identical with the cross-section of the stack, were adopted following an examination of the economical and technical aspects of the problem.
5. In order to combat the influence of polarized surface layers at the membranes, layers which tend to increase the direct current energy consumption and the formation of scale on the anodic side of the anionic membranes, more or less turbulent flow conditions are promoted. This is accomplished by the application of sufficiently high flow rates in combination with the separators mentioned under (2). These separators tend to encourage a state of forced turbulence at comparatively low flow rates. The lowest possible flow rate is called the critical depolarization velocity. It is essential to operate the unit at this or higher velocities.
6. All the membranes are placed in a vertical position and the direction of flow of all the liquids is from bottom to top in order to avoid a possible accumulation of gases in the apparatus. The flow in alternate compartments is slightly cross-wise as a result of the four-hole filter press arrangement, but it is not a counter-current one. Thus, if approximately the same flow rates are applied in alternate compartments, only minor pressure differences will occur between the liquids on either side of the possibly fragile membranes; the advantages of this are evident.

Counter-current flow, which may be advantageous as regards current efficiency in the case of prolonged desalting (great differences in concentration) and comparatively poorly selective membranes, can be incorporated in the flow sheets of any plant comprising a number of stacks in series, the flow directions in the individual stacks being parallel.

A picture of the completely assembled apparatus is given in Plate XIX. This is a more or less "exploded view" of the total membrane press; for the sake of clarity, a few sub-divisional membrane stacks have been removed.

A picture of the apparatus in actual operation is given in Plate XX.

OPERATION

The units can be used batch-wise as well as continuously. The actual flow rate that should be applied within the compartments is prescribed by the critical depolarization velocity. In the case of large plants comprising a great many units it will always be possible to design a flow sheet for continuous operation in such a way as to ensure the required flow rates for each unit: this is done by means of various series and parallel connexions between the units or between the various subdivisional stacks. In the case of small plants and great desalting ranges this is not possible. In this case a choice has to be made between either batch-wise operation, which is the most economical method, or a continuously recycling system with continuous supply of raw water and withdrawal of fresh water at the rate given by the throughput required. The latter method has the disadvantage of operating exclusively at the lowest occurring salt content, i.e. at the highest electrical resistance. Consequently it involves a higher energy consumption. Intermediate cases may consist in the application of a few recycling systems in series.

One such case is the single unit of 40 × 100 cm. membranes used for a field test which has been carried out with North Sea water at Scheveningen Harbour, on the Dutch coast. In this test the subdivisional stacks have been incorporated into three different recycling systems operating at effluent concentration levels (C_1) of approximately 5,000, 1,500 and 300 ppm. Cl respectively. Sea water (18,000 ppm. Cl) is introduced into the first cycle and fresh water (300 ppm. Cl) is withdrawn from the third cycle at approximately the same rate (36 m.^{3} daily). The concentration of the liquids entering the stacks (C_0) is obviously considerably higher as a result of mixing with the feed water or with the cycle overflow from the previous cycles. In each the percentage reduction of the salt content $\left(\frac{C_0 - C_1}{C_0} \times 100 \text{ per cent}\right)$ amounts to approximately 40 per cent.

PERFORMANCE DATA OF THE 40 × 100 CM. UNIT

The capacity of a given electrodialyser depends on the concentration of the water to be desalted and on the average current density applied. The value of the latter quantity has to be adapted to the concentration in such a way as to obtain the proper balance between the cost of capital outlay (inversely proportional to the current density) and the energy consumption per unit of fresh water produced (proportional to the current density). A review of the possible capacities of the unit of 40 × 100 cm. is given in Table 3, together with the estimated optimal values for the current density. These data refer to a standard unit comprising 2 × 400 membranes. In addition, a set of experimental values for the energy consumption has been included. The latter values hold only for one particular type of membrane (resistance 10–15 ohm · cm.^{2}, measured in 0.1 N NaCl). With other types of membrane other figures will be obtained.

THE MEMBRANES

The greater part of the membranes that were used in the field test with North Sea water at Scheveningen Harbour (Netherlands) were of a heterogeneous type. They were

TABLE 3. Performance data of electrodialyser with 800 membranes measuring 40 × 100 cm.

Water type	Desalting range	Estimated optimal average current density (mA./cm.^{2})	Capacity (1,000 U.S. gallons per hour)	Energy consumption kWh./1,000 U.S. gallons
Sea water	20,000 ⟶ 300 ppm. Cl	40	0.67	150
Highly brackish water	5,000 ⟶ 300 ppm. Cl	20	1.33	30
Hard moderately brackish water (containing Ca, Mg, SO_4 in addition to NaCl)	4,000 ⟶ 500 ppm. total solids	15	2.00	18
Slightly brackish water	1,000 ⟶ 300 ppm. Cl	10	4.67	4

sheets of a mixture of a plastic and an ion exchange material. The resistance of these membranes was 10–15 ohm · cm.^{2}. All the cost price data were calculated on this basis.

It is to be expected that membranes of a lower resistance will become available in the near future. The properties of the sheets produced by TNO on a semi-technical scale are to be found in figs. 4 and 5.

The good quality of these membranes will considerably lower the cost price of fresh water produced from sea water. A large amount of salt is to be removed from sea water while the sea water has a low electric resistance. In this part of the demineralization process most of the voltage is used to counterbalance the voltage drop across the membranes. When this is improved by a factor of 3 or 4 the energy consumption will decrease and the cost price of the water will go down by about $1. When the price of membranes goes down as a result of mass production, prices even lower that those mentioned in the last paragraph of this article as target values may be obtained.

PRODUCTION OF APPARATUS

As stated in the introduction to this paper, the development work on the apparatus described was sponsored by various countries. Production of apparatus has or will be undertaken: (a) in France, by Société pour la Déminéralisation par l'Électrodialyse, 5, rue Berthezène, Algiers; (b) in The Netherlands by Messrs. Bronswerk, Eemstraat 91, Amersfoort; (c) in the United Kingdom by Messrs. William Boby, Rickmansworth, Hertfordshire.

THE COST PRICE OF WATER AND THE REQUIRED CAPITAL OUTLAY

In Table 4 a summary is given of the cost of electrodialytic water-desalting, calculated according to the standards suggested by the Office of Saline Water of the United States Department of the Interior.

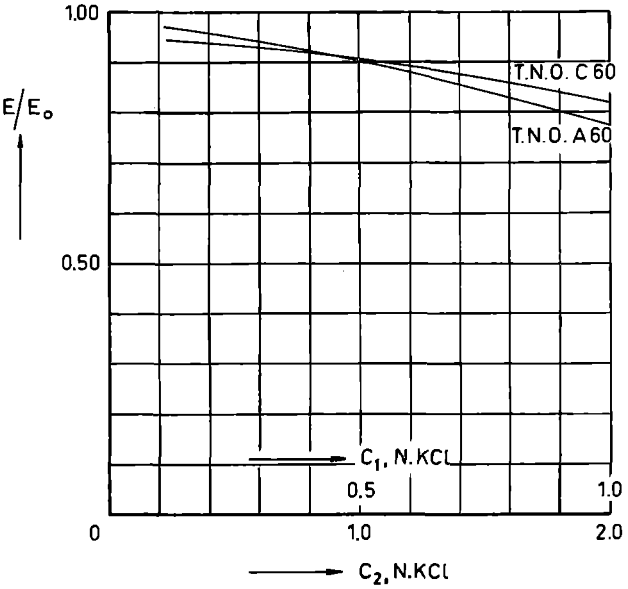

FIG. 4. Selectivity expressed as membrane potential ratio (E/E_0) as a function of the concentrations C_1 and C_2 of the KCl solutions on either side of the membrane.

The result of a cost estimate largely depends on basic assumptions such as wages per man-hour, power costs, etc. This can lead to very different results and can cause considerable confusion, especially with such a process as that under consideration, which will be applied in different parts of the world under widely varying local conditions. For this reason the Office of Saline Water has suggested standards for making comparative cost estimates. If local conditions differ greatly from these standards, the calculated results lose much of their absolute significance. This applies, though to a lesser extent, even to the relative values of these results. However, as long as the problem is to be considered in general terms, there is no other possibility. One can, of course, dispute the value of the assumed standards which, in this case, are based on typical American conditions: naturally the more the local conditions, as known to the reader, differ from these typical American ones the more will he be inclined to do so. It may be pointed out, for instance, that these standards include a wage of $6,250.— i.e. approximately 24,000 florins per man per year (including pay roll extras and general overheads), a 40-hour working

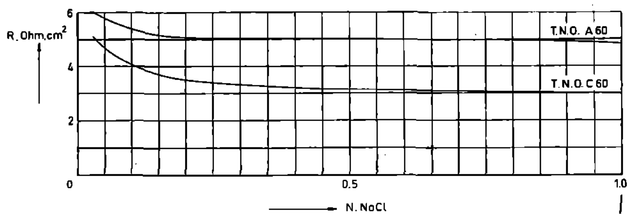

FIG. 5. Membrane resistance as a function of the concentration of an NaCl solution.

TABLE 4. Electrodialytic water desalting: cost estimate according to American standards

	Small production capacity (10,000–100,000 tons of fresh water per year)		Large production capacity (10 million tons of fresh water per year)	
Type of water	Total production cost per unit of fresh water produced ($ per 1,000 U.S. gallons)	Capital outlay per unit of production capacity to be installed ($ per 1,000 U.S. gallons per day)	Total production cost per unit of fresh water produced ($ per 1,000 U.S. gallons)	Capital outlay per unit of production capacity to be installed ($ per 1,000 U.S. gallons per day)
Sea water	5.00	4 000	4.00	3 500
Hard brackish subsoil water (North Africa, salt content $^{1}/_{8}$ of that of sea water)	0.80	700	0.65	500
Moderately brackish mine water (South Africa, salt content $^{1}/_{12}$ of that of sea water)	0.60	500	0.45	400
All types of water cost of distillation	5.00	5 500	1.50	2 000

week and an electric power cost (direct current) of only $0.01 (3.8 Dutch cents) per kWh.

Table 4 shows total production costs in dollars per 1,000 U.S. gallons of fresh water and also the capital outlay required expressed in dollars per 1,000 U.S. gallons per day of production.

The total production costs include interest and depreciation on invested capital. The figures apply to three different types of water, each typical of an extensive area. In addition various figures are given for small and large production respectively. "Small" production suggests an installation of the size of the pilot plant at Scheveningen, viz. about the smallest unit that it is economically and technically justifiable to use in practice.

The minimum production for the various types of water varies between 10,000 and 100,000 m.[3] per year. These figures may be considered in the light of our present domestic water consumption of approximately 100 litres per head per day (this figure was measured for a residential area in Amsterdam). On the basis of this figure the installation at Scheveningen could provide the domestic water supply for 300 to 3,000 persons, depending on whether sea water or moderately brackish water is available as a starting material.

The possibilities of processing brackish water are obvious. At the moment there are no other processes with which similar results can be obtained. For the conversion of sea water the prospects are less favourable, even if it is assumed that with further improvements (better and cheaper membranes) conversion costs may drop to $2–$2.50 per 1,000 gallons of fresh water. This may well occur, as modern distillation techniques are expected to produce fresh water on a large scale at a cost of approximately $1.50 per 1,000 U.S. gallons (this estimate takes into account the standards discussed above). Yet, there are big possibilities of applications here also, for instance in motor vessels, where the electrodialytic process leads to appreciably lower fuel consumption as compared with the distillation process. In large stationary installations, economically suitable combinations of power generation, distillation and electrodialysis may also be envisaged. In the case of small sea water conversion units, electrodialysis appears to have the advantage of a somewhat smaller capital outlay as compared with distillation.

RÉSUMÉ

Le procédé électrodialytique de déminéralisation mis au point par l'Institut technique central TNO des Pays-Bas avec le concours de différents pays (J. Hamaker)

Pendant les dernières années de la seconde guerre mondiale, on avait effectué des recherches sur la déminéralisation des solutions en vue de produire certaines substances de grande valeur dans une économie de guerre. Dès la fin des hostilités, ces recherches furent poursuivies, afin notamment de tirer des protéines du petit-lait. La déminéralisation était assurée par électrodialyse dans un appareil à trois compartiments séparés par des membranes non sélectives.

Lorsque les Pays-Bas commencèrent à s'intéresser à la déminéralisation des eaux saumâtres, les travaux prirent plus d'ampleur, et les chercheurs étudièrent la possibilité d'utiliser des membranes sélectives. Les différentes institutions dépendant de l'organisation industrielle TNO, y compris l'Institut technique central, entreprirent alors de produire de telles membranes et de mettre au point les appareils nécessaires.

Au cours d'un débat à l'OECE, auquel participèrent les représentants de différents pays d'Europe ainsi que de certains États du Commonwealth, une comparaison fut établie entre les prix de revient de diverses méthodes de déminéralisation. Il apparut alors que l'électrodialyse était ordinairement le plus économique de tous les procédés de déminéralisation de l'eau saumâtre, c'est-à-dire de l'eau contenant en solution de 500 à 30 000 ppm de solides divers. On décida en conséquence que huit pays aideraient le TNO à poursuivre ses travaux.

Grâce à cette coopération et aux efforts déployés dans un pays pour perfectionner les procédés inventés par le TNO, on construit maintenant des installations de déminéralisation par électrodialyse pour les mettre en vente ou les fournir à des propriétaires d'entreprises privées.

On peut décrire succinctement comme suit les principales caractéristiques de l'appareil mis au point en collaboration par les pays associés aux travaux, et qui fonctionne depuis lors de manière satisfaisante.

Cet appareil renferme 800 membranes mesurant $0{,}4 \times 1{,}00$ m².

Il peut traiter en une heure de 2,5 à 3 mètres cubes d'eau saline contenant de 20000 à 1000 ppm de Cl^-, pour une consommation d'énergie allant de 40 à 1 kWh par mètre cube. Les membranes ont une résistance électrique de 10–15 ohm · cm² dans 0,1 N NaCl.

D'après les évaluations faites voici quelques années pour le compte de l'OECE, la déminéralisation par électrodialyse était à l'époque le plus économique de tous les procédés de purification connus pour les eaux dont la salinité varie entre environ 300 ppm de Cl^- et la concentration de l'eau de mer. Cette constatation reste valable aujourd'hui. D'autre part, l'eau douce obtenue n'a pas un prix de revient exagéré si elle est destinée à la consommation humaine. Dans certaines conditions, une eau faiblement saline peut aussi être traitée par ce moyen pour servir à l'irrigation.

Là où les conditions locales sont favorables, on peut s'attendre à ce que le procédé électrodialytique soit également appliqué à la déminéralisation de l'eau de mer.

DESIGN CONSIDERATIONS IN ELECTRODIALYSIS PLANT FOR SALINE WATER DEMINERALIZATION

by

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INTRODUCTION

The practical application of electrodialysis to saline water problems is at present in too early a stage for a critical review of trends in the design of electrodialysis equipment to be attempted. The scope of the present paper is, therefore, restricted to a consideration of some important factors that influence the development of electrodialysis apparatus for use in water demineralization.

Certain obvious factors which influence the design of apparatus are the concentration range over which demineralization is desired, the mean current density applied, and the nature of the membranes it is intended to use. These three factors are interrelated and, in most instances, the only independent variable is the range over which demineralization is desired. Thus, the choice of mean current density is influenced by the concentration limits of the diluting stream (or "dialysate") in the electrodialysis apparatus, since it is feasible to apply relatively high current densities only if the concentration is high; otherwise excessive power consumption, and possibly a detrimental degree of polarization, occurs. Regarding the other point mentioned, the nature of the membranes used, it is difficult to indicate clear directions as to the choice of membranes for a particular desalting purpose. The development of permselective membranes for use in electrodialysis is being actively pursued at the present time, the object being to obtain highly permselective membranes which are mechanically strong and inexpensive. An account has been given [9][1] of the lines along which membrane development has been carried out in South Africa, where the first object has been to prepare membranes suitable for the desalting of brack water from the Orange Free State gold mines (total dissolved solids content, 4,000 parts per million, of which about 90 per cent is sodium chloride). In this case, inexpensive membranes having high permselectivity over a limited concentration range were prepared. Although improvements have been made, the first membranes prepared were of limited mechanical strength, and this fact made it important do design electrodialysis apparatus in which small liquid pressure changes occur during operation.

OHMIC LOSS IN ELECTRODIALYSIS APPARATUS

The energy required to drive an electrodialysis process is the sum of contributions of the three general types: the thermodynamic "minimum work" [7] required to effect the basic electrolyte transfer process, the ohmic loss suffered in passing current through the membranes and liquids (which is lost as low-grade heat), and losses suffered in applying this current by means of electrodes (these are partly ohmic in character and partly due to the need to overcome the over-potentials acting at the electrodes).

It is with a view to minimizing the number of electrodes required for a given electrodialytic operation that multicompartment electrodialytic apparatus has been evolved [4, 10], the success of which depends upon the use of highly permselective membranes. In such multicells, when operated at practical values of current density, it has been found that the major energy requirement is that to overcome ohmic resistance in the liquids and, to a lesser extent, in the membranes. The membrane effect has become relatively unimportant with the evolution of highly permselective membranes of low resistance. The remaining problem is, therefore, that of the resistance of the saline liquids, which imposes a lower concentration limit to the economic application of electrodialysis.

In order to minimize ohmic loss in the liquids, the least possible spacing between adjacent membranes must be achieved in apparatus design [10]. The limitations governing membrane spacing are due to the need to distribute liquid evenly to a large number of alternate compartments (which are in most cases hydraulically in parallel), and due to pressure loss suffered in passing liquid through

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[1] The figures in brackets refer to the bibliography on page 362.

narrow compartments. Most current apparatus design is based on a membrane spacing of 0.75 to 1.5 mm.

POLARIZATION IN ELECTRODIALYSIS

The most important interfering factors in the application of electrodialysis to desalting problems are due to the occurrence of polarization at the interfaces between solutions and permselective membranes [6]. Events at a polarized interface between a single electrolyte solution and a permselective membrane can be considered by supposing a Nernst diffusion layer to exist in which, in the steady state, the constant concentration gradient is

$$\frac{dc}{dx} = \frac{(\bar{t} - t)\, i}{\mathrm{FD}} = \pm \frac{(\mathrm{C} - \overline{\mathrm{C}})}{(\delta)} \tag{1}$$

where

$\bar{t}$ = the transport number of the counter ion in the membrane phase (e.g. of the cation if the membrane under consideration is cation-permeable),
t = the transport number of the same ion in free solution,
i = the applied current density,
D = the diffusion coefficient of the electrolyte,
C = the electrolyte concentration in the bulk of the solution,
$\overline{\mathrm{C}}$ = the electrolyte concentration in the immediate vicinity of the membrane,
δ = the thickness of the diffusion layer,

[the positive sign applies to $(\mathrm{C} - \overline{\mathrm{C}})/\delta$ when a dialysate compartment is considered].

Equation (1) is the simplest form of relation describing polarization; no account is taken in it of the effect of electrolyte diffusion through the membrane. The thickness of the diffusion layer, δ, is a function only of hydrodynamic conditions in the compartment under consideration. If its value is known under given steady conditions in an electrodialysis apparatus, equation (1) enables the concentrations, $\overline{\mathrm{C}}$, in the immediate vicinities of each membrane to be estimated from the bulk concentrations, C.

The existence of lower concentrations in the dialysate compartments, and of higher concentrations in the brine compartments, than the respective bulk solution concentrations, can give rise to adverse effects:

1. If $\overline{\mathrm{C}} \ll \mathrm{C}$ in the dialysate compartment
   (a) the compartment has an unduly high electrical resistance;
   (b) if $\overline{\mathrm{C}}$ approaches zero, a significant part of the current passing through the membranes is borne by ions arising from the dissociation of water.
2. If $\overline{\mathrm{C}} > \mathrm{C}$ in the brine compartment, the solubility product of any precipitate-forming ions present may be exceeded in the region adjacent to the membranes, and a scale can accumulate on the membranes as a result.

These possibilities are now discussed in turn.

1(a). In the dialysate compartment, $\overline{\mathrm{C}}$ becomes zero when

$$\frac{i}{\mathrm{C}} = \frac{\mathrm{FD}}{\delta_{\mathrm{crit}}\,(\bar{t} - t)} \tag{2}$$

It is most convenient, in the present context, to speak of a limiting value δ_{crit}, of δ which obtains in the case of $\overline{\mathrm{C}} = 0$; it is, of course, equally feasible to speak of limiting values of i or C. Experimentally, it has been found in work with the intermembrane spacer type of electrodialysis apparatus (see later) that δ is inversely proportional to the velocity, v, of liquid flow in the compartment under consideration and to the distance, d, between the membranes forming the compartment:

$$\delta = \frac{k}{vd} \tag{3}$$

where k is a constant, so that equations (2) and (3) define a critical velocity, v_{crit},

$$v_{\mathrm{crit}} = \frac{k\,(\bar{t} - t)}{\mathrm{FD}} \; \frac{i}{\mathrm{C}\,d} \tag{4}$$

Thus, for a given electrolyte and membrane system:

$$v_{\mathrm{crit}} = \frac{k'\,i}{\mathrm{C}\,d} \tag{5}$$

where $$k' = \frac{k\,(\bar{t} - t)}{\mathrm{FD}}$$

Equation (5) applies at any point along the path of liquid, i.e., for definite values of i and C. In practice, these quantities vary throughout the path of liquid in a compartment, but it is possible to describe v_{crit} in terms of the mean current density, $\bar{i}$, and the dialysate concentration limits, C_0 (initial value) and C_1 (final), by means of the integrated form

$$v_{\mathrm{crit}} = \frac{k'\,\bar{i}}{\overline{\mathrm{C}}\,d} \tag{6}$$

where $$\overline{\mathrm{C}} = \frac{\mathrm{C}_0 - \mathrm{C}_1}{\ln\,(\mathrm{C}_0/\mathrm{C}_1)}$$

which applies to parallel-sided apparatus (constant velocity) in which the local current density is proportional to the dialysate concentration. Experiments indicate that the latter condition is obeyed under practical conditions to a reasonable degree, deviations greater than about 15 per cent being rare except when very wide concentration ranges are involved. Despite the limitations concerning the validity of equation (6), it has been found useful in design work.

Fig. 1 shows values of v_{crit} plotted against $\frac{\bar{i}}{\overline{\mathrm{C}}\,d}$ which were obtained in pilot plant work. Both types of compartment were filled with a perforated, corrugated spacer material as described by Volckman and Moyers [9], and velocities were computed on the basis of an "open cell", i.e., neglecting the presence of this material. Determinations of v_{crit} were made by choosing fixed values of dialysate inlet concentration and mean current density, and then determining the values of applied potential required to produce this current when dialysate was passed at various rates. The applied potential was then

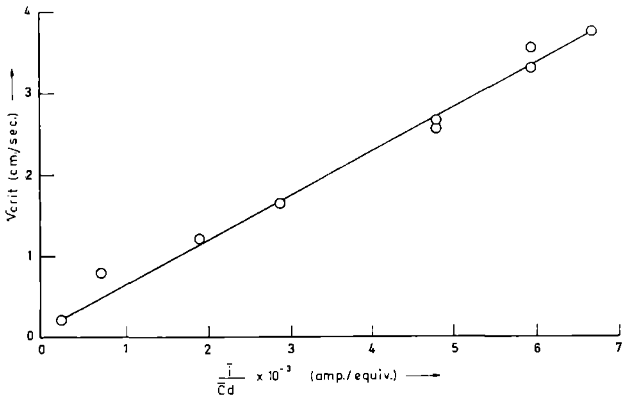

FIG. 1.

plotted against flow rate and the flow rate value immediately below which a sharp increase in potential was found was taken to give the critical velocity. In obtaining the results shown in fig. 1, current densities were varied between 4 and 37 mA./cm.^{2} and inlet dialysate concentrations between 30 and 300 meq./l. sodium chloride. It was possible to test only two values of membrane spacing, *d*, namely 0.85 and 1.6 mm.; these involved the use of two different corrugated perforated spacer materials. The two materials used had essentially similar configurations. The membranes used were made by treatment of parchmentized paper [9].

The straight-line relationship of fig. 1 has been taken as experimental verification of equation (6), and therefore also of (3). The constant *k*, derived from the slope, *k'*, of fig. 1, can be regarded as a hydrodynamic characteristic of the system: in the present case it is a characteristic of the spacer material.

There is evidence that *k'* in equation (6) depends on the nature of the membranes used, but it is not yet clear whether this is a true hydrodynamic effect (due possibly to the topography of the membrane surface) or due to the neglect of back diffusion of electrolyte through the membranes in the above simple treatment. The effects noticed are greater than can be accounted for by the factor ($\bar{t} - t$) in equation (4).

1(b). It has been observed [6] that participation in electrodialysis by hydroxyl and hydrogen ions is more severe at the anion-permeable than at the cation-permeable membrane. For this reason, more OH^- passes out of the dialysate compartment than H^+, and the dialysate stream consequently tends to become acidic. Although it is generally possible to prevent serious acid formation in the dialysate, a very small amount of hydroxyl ion transfer through the anion-permeable membrane is responsible for one of the major difficulties in the electrodialytic treatment of natural waters, namely, the precipitation in the brine compartments of magnesium hydroxide and calcium carbonate.

2. Alkaline conditions in the vicinity of the anion-permeable membrane on its brine compartment side combine with the excess concentration occurring there to favour the precipitation of constituents which are sensitive to alkali. If, after the accumulation of a certain amount of such a deposit, the polarity of the electrodes is reversed and the feed and outlet streams interchanged (so that the brine does not become desalted, and *vice versa*), then acid conditions are caused to prevail in the vicinity of the deposit; these, under favourable conditions, can cause it to redissolve. This illustrates the application of polarity reversal [1] to control the formation of acid-soluble scales in electrodialytic apparatus. The same applies to deposits in the cathode compartment, while the method is effective also with acid-insoluble scales.

BASIC DESIGNS AND MODES OF OPERATION OF ELECTRODIALYSIS APPARATUS

Solutions along two distinct lines of approach have been found for the basic problems—ohmic resistance and polarization—in the design of electrodialysis apparatus. The characteristic features of the two basic types of apparatus, both of which are in the advanced development stage, are described in the following section.

"*Tortuous path*" *apparatus*

In the "tortuous path" apparatus [3], a relatively narrow, but long, liquid path traversing the membrane surface is employed (fig. 2). The path is formed from a gasket, the thickness of which gives the desired membrane spacing. With this arrangement, liquid introduction to the interior of the unit is generally achieved by forming a conduit of registering holes in the gaskets, and providing suitable slots to connect each conduit with the appropriate compartments. Although apparatus of this type can function with the liquid path entirely unobstructed, it has been found advantageous to cause the liquid to flow over small "bridges" during its passage along the path, the object of the "bridges" being to minimize polarization at a given flow velocity, in other words, to reduce the value of *k* in equation (3). A calculation from the results given by Rosenberg and Tirrell [6] has indicated a value of *k* for this system of about 0.016 cm.^{3}/sec., the basis of this calculation being the anion polarization in Rosenberg and Tirrell's "Run 12", and transport number values of $\bar{t} = 0.95$ and $t = 0.62$ for the system studied by them (sodium chloride with highly permselective membranes).

The "intermembrane spacer" apparatus

In this type of apparatus the gasket acts essentially only as a frame to form the outer walls of each compartment (fig. 3). A spacer material (8), such as perforated, corrugated plastic sheet, fills each compartment and serves to hold the membranes at an accurate distance apart and

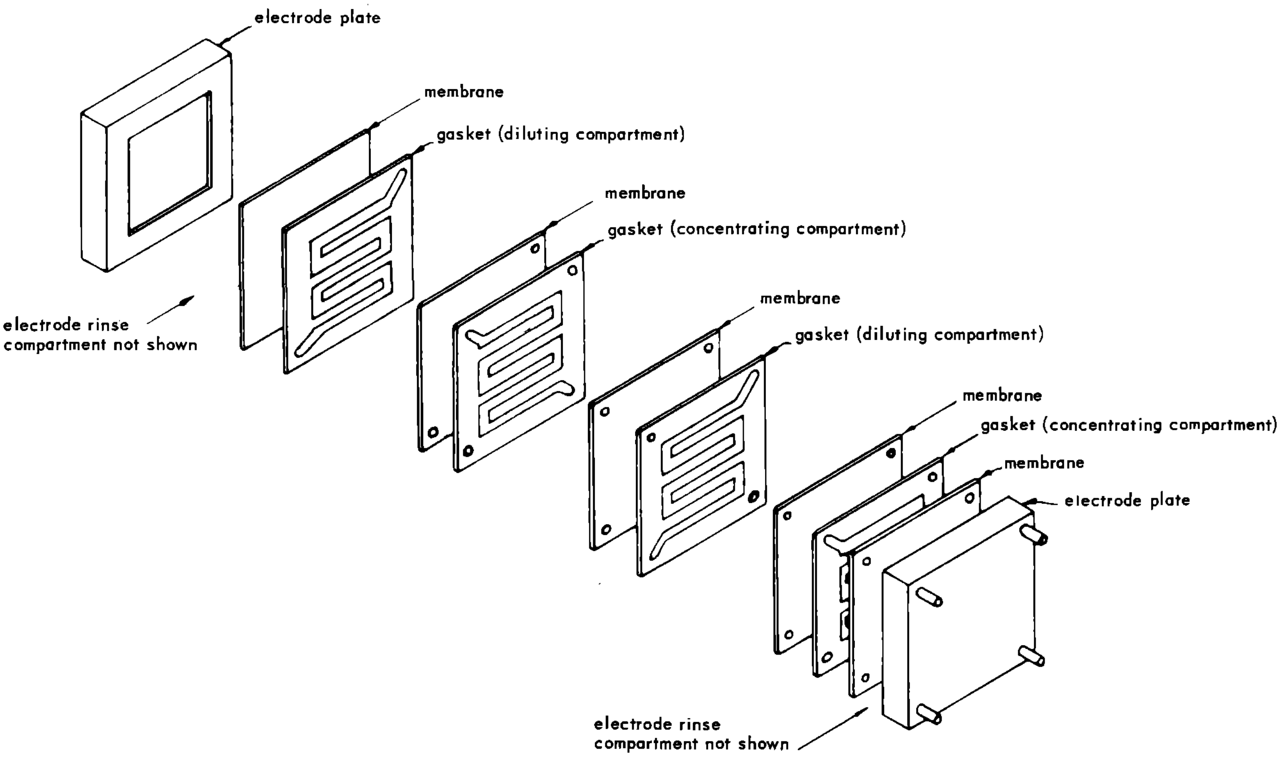

FIG. 2. Exploded view of tortuous path unit.

to promote eddy formation in the flowing liquid. Using the same basis for calculation as was adopted in computing the value of k [equation (3)] for the apparatus of Rosenberg and Tirrell, the results of fig. 1 obtained using a perforated, corrugated polyvinylchloride spacer yield a k value of 0.0024 $\text{cm.}^3/\text{sec.}^{-1}$. Although a quantitative comparison of the performance of the two types of apparatus is of doubtful value, because equation (3) has been verified only for the intermembrane spacer system over limited ranges of concentration and current density (Rosenberg and Tirrell adopted with some success a quite different correlation of results) and also because the criterion of the limiting condition was different in the two sets of experiments, the results suggest a definite action on the part of the spacer material in reducing the thickness of the diffusion layer at a given liquid velocity. It may be noted that this velocity was computed for the intermembrane spacer system on the basis of an open cell, so that appreciably higher velocities occur locally in the cell.

Comparison of the two types of apparatus

The tortuous path type of apparatus provides a long desalting path within a compact apparatus, and is, for this reason, suited to applications in which desalting between wide concentration limits is desired. An advantage accruing from the absence of spacer material is the low electrical resistance obtainable; typical perforated, corrugated materials increase ohmic resistance by 40–50 per cent compared with open cells.

The use of a long, baffled path in the tortuous path apparatus causes a high frictional pressure loss by the liquids, relatively high liquid velocities being required because of the tendency towards high k values. Pressure losses per unit of the order of two atmospheres have been reported for tortuous path apparatus at operating velocities when dealing with brack water [8]. On the other hand, pressure losses of the order of 2–3 ft. head of water occurred per unit in the South African pilot plant trials on intermembrane spacer apparatus. The exposed membrane areas were of the same order in the two cases, 187 and 128 in.^2 respectively.

The existence of relatively large areas of unsupported membranes in the tortuous path apparatus, together with the rather large pressures encountered at the inlet ends, makes it important to avoid pressure differences across the membranes between brine and dialysate streams. If the two types of compartment are identical, this is done by running these streams in concurrent flow at equal rates through the apparatus. Recirculation of one stream, generally the brine, must be carried out in order to do this in those cases in which equal throughput rates of these streams are not desired in the demineralization plant. In the intermembrane spacer apparatus, unlike flow rates can be used provided the spacer material and membranes are mechanically satisfactory, so that less recirculation is required than in the tortuous path apparatus. Use can in fact be made of the "bowing" of membranes caused by a pressure difference between the two streams in an apparatus. In a scheme that was successfully used with the intermembrane spacer type of apparatus, the brine was run at a quarter the flow rate of the dialysate and a pressure head was applied to the brine issuing from the apparatus so that the pressures of the two streams at the inlet were equal. The pressure of the brine stream at points in the apparatus other than the inlet was therefore greater than that of the dialysate, so that the membranes were pressed firmly against the spacer in the dialysate compartments. This ensured that the lowest possible ohmic resistance was obtained with the cell construction adopted.

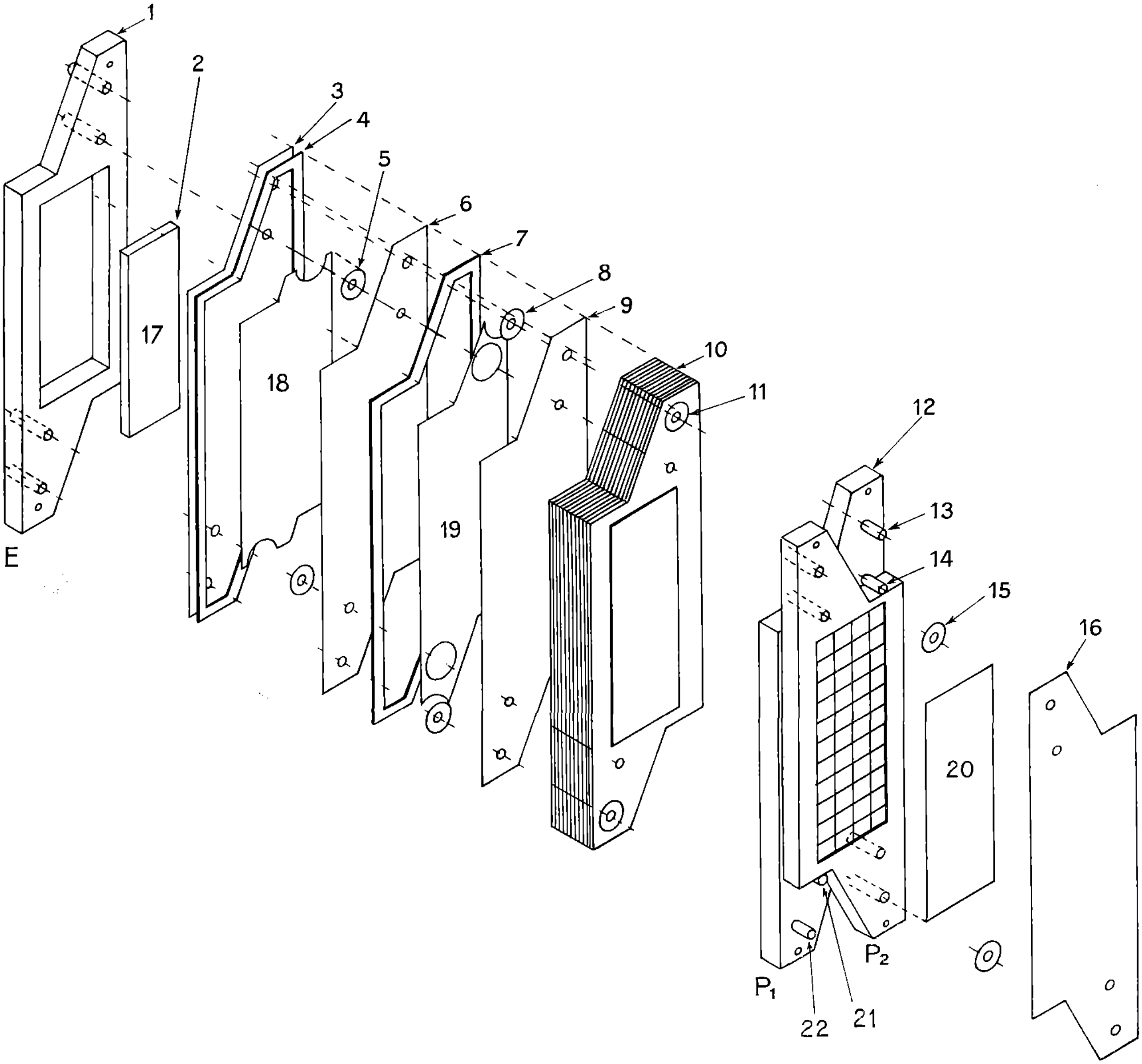

FIG. 3. Exploded view of membrane pack. 1. Electrode plate; 2. electrode rinse compartment, not shown; 3. membrane; 4. gasket; 5. distribution ring (dialysate); 6. membrane; 7. gasket; 8. distribution ring (brine); 9. membrane; 10. membrane pack; 11. rubber ring; 12. intermediate plates; 13. brine outlet; 14. dialysate outlet; 15. rubber ring; 16. membrane; 17. electrode; 18. spacer material diluting compartment; 19. spacer material concentrating department; 20. spacer material; 21. dialysate inlet to pack; 22. brine inlet to pack.

Liquid distribution in electrodialysis apparatus

The problem of separate liquid distribution to sets of alternately placed narrow compartments in electrodialytic multicells has been dealt with in two general ways. In one method, the distribution conduits are formed from rigid annular rings ("distribution rings") having radial openings through which liquid can flow. These can be made of a thickness equal to twice the desired thickness of the compartment, in which case a membrane-to-membrane seal is made in that compartment which it is not desired to feed. Alternatively, conduits can be built up from annular rings which alternately have and have not radial openings. Distribution rings have been much used in intermembrane spacer apparatus. In the second method, which can be used with either type of apparatus, the cell wall, or gasket, and distribution system are generally integral, the conduits being formed from holes in the gaskets, and slots being either cut or not cut from the conduit to the cell space according to whether connexion is required between the conduit and the cell or not. The slots must be of sufficient width to pass the flow required, but not so wide as to permit cross-leakage due to inadequate membrane support. Experimentally a slot width of about 2 mm. has been found satisfactory.

It may be noted that feeding a compartment from a single point or region, e.g. a single distribution ring or slot, is undesirable when a large cell area is used. The best solution would appear to be the provision of a number of conduits in parallel, each connecting with the appropriate compartments by means of separate slots.

Modes of operation

The counter-current principle has been more or less discarded in the operation of electrodialysis plant mainly for the reason of avoiding substantial pressure unbalance in the plant due to the frictional pressure losses. Another reason that is of importance in apparatus placed vertically is that removal of trapped air in such apparatus is facilitated by flowing both streams upwards.

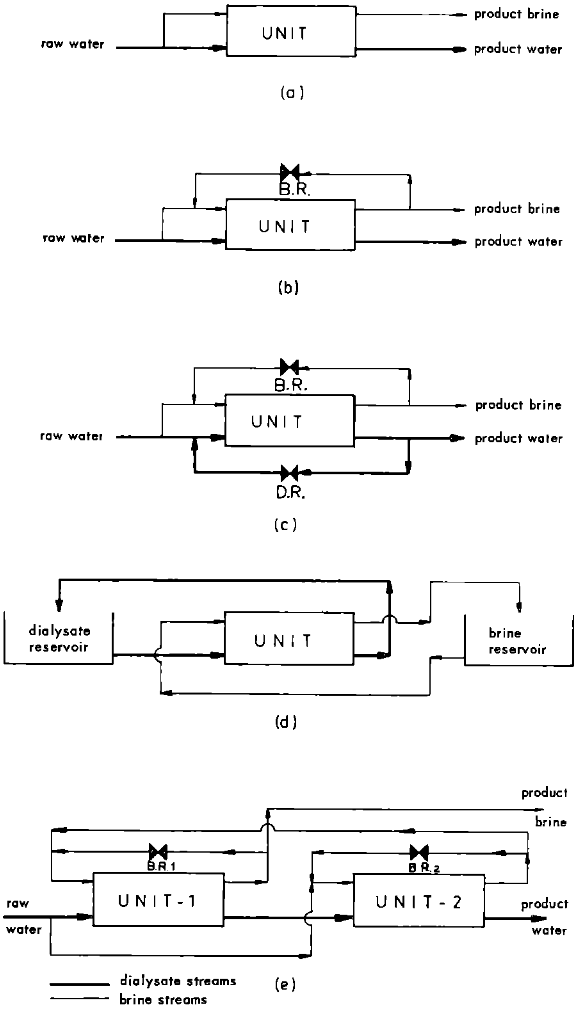

Fig. 4. Schemes for the operation of electrodialysis plant with concurrent flow.

Fig. 4 shows typical schemes for the operation of electrodialysis plant with concurrent flow; the simplest of them, given by fig. 4(a), is feasible only if long path apparatus is used and substantially similar throughput rates of the two streams are permissible. This could be the case with small installations situated at an ample source of saline water and where disposal of a voluminous brine stream is possible, e.g. in remote areas having ample underground water. The scheme of fig. 4(b), in which brine recirculation has been added, makes it possible to reduce the brine throughput rate and consequent disposal problem. This method is best used with tortuous path apparatus. Although wide desalting ranges can be achieved in any type of unit using the principle of 4(c), an important disadvantage is that the mean concentration of dialysate in the unit is close to that of the product water if the degree of recycle is high. There is consequently unnecessary ohmic loss.

The "batch recycle" system, illustrated in fig. 4(d), is one which enables any apparatus to be used for virtually any desalting purpose. Both streams are circulated through the electrodialysis unit from reservoirs, the circulation rate being chosen according to the velocity required to secure adequate depolarization. A convenient method of employing the batch recycle system is to apply a constant voltage to the electrodes of the apparatus throughout the desalting cycle. Then, as the dialysate becomes desalted, the current density falls because of the increasing resistance. If these events occur at the same rate, and if equation (6) is obeyed, the depolarization velocity remains constant throughout the cycle. Although these simple relationships are not obeyed strictly in practice, e.g. the resistance contributed by the brine stream decreases with the progress of each cycle while that due to membranes varies little, the method works well in practice provided conditions at the commencement of the cycle are fairly remote from the limiting conditions (liquid velocity 50–100 per cent higher). In a modification of this system, batch recycle is applied to the dialysate only, and the brine operated on normal recycle so that it is of constant concentration.

Fig. 4(e) illustrates a continuous, stagewise, semi-counter-current mode of operation that has been successfully used in pilot plant experiments with the intermembrane spacer type of apparatus. Four stages were employed in pilot plant trials on Orange Free State gold mine water. The dialysate stream passed without recirculation from stage 1 to stage 4. The brine stream entered into stage 4 and passed to stage 1, with recycle being applied at each stage. The advantage of this system is that concentration differences across membranes at the outlets of the units are kept as small as possible, the difference being smaller the greater is the number of stages. The large-scale desalting plant now being erected in South Africa is to have two stages operated in this way; although equipment for brine recycle is incorporated, it is intended to run without it if it proves feasible.

Demineralization apparatus that is required to serve small groups in arid areas must operate reliably with very little supervision and with the minimum of ancillaries. It may even be the case that pumping is not available. If so, the mode of operation given in fig. 4(a) is the only one possible. If pumping and suitable storage are available, the batch recycle system can be employed to produce water of ordinary drinking quality by means of electrodialysis units of either type.

DEVELOPMENT OF INTERMEMBRANE SPACER ELECTRODIALYSIS APPARATUS

The original development of this apparatus took place in The Netherlands [5], and further work in South Africa has been concerned with its application to a specific problem on a large scale. For this reason, relatively large units of a specialized character have been evolved rather than a standardized small unit. From the point of view of capital cost, it would seem to be sound to plan a plant having a small number of large units rather than a large number of small ones [8].

The course of developments in South Africa has been described elsewhere [9], but especial attention is now directed at some aspects that became apparent in pilot plant trials. These were:

1. Poor intercompartmental distribution of liquid set in (with consequent excessive polarization) if the maximum velocity in a conduit feeding many parallel compartments exceeded about 100 cm./sec.
2. The conduits could not be enlarged indefinitely because of a wastage of available membrane area and the occurrence of a significant amount of electrical short-circuiting through large conduits.
3. It is desirable to have a large number of desalting units ("cell pairs") per electrode pair. The fraction of the total power which is lost at electrodes is very small if this number is more than about 50, but the ultimate deciding factor is the fact that the materials required for use as electrodes and electrode holders (end-plates) are specialized in nature, and it is economically desirable to use as few electrodes as possible.

   Rinsing by means of separate streams of saline water is necessary in the electrode systems, and, although these liquids can be returned to, say, the pretreatment section of an integrated demineralization plant (cathode rinse product being used to aid in the precipitation of heavy metals, and anode rinse product for re-acidulation and chlorination after filtration), it is clearly desirable to limit the amount of piping and pumping required in excess of that connected with the main streams in a plant.

   It was therefore thought desirable to limit the number of electrode pairs in a plant to less than would be desirable on a consideration of power losses alone.
4. Relatively heavy equipment is required to seal multicompartment apparatus of large cross-section.
5. Multicells containing very many membranes are not easily handled. Maintenance becomes difficult with a very large stack.
6. If brine and dialysate flow rates are not chosen equal, but regular polarity reversal is to be used to control the accumulation of deposits on membranes and electrodes, both liquid circuits should be capable of handling whichever flow is normally at the higher rate.

The difficulties 1–5 above have been greatly reduced by the adoption of a method [2] of subdividing a multicell apparatus containing a large number of cell pairs (a "press") into a number of smaller units ("packs"). These are bounded on either side by plates ("intermediate plates") which have openings in their central part that provide a path for the passage of the transverse electric current, the latter being conducted by a concentrated electrolyte solution (the ultimate brine stream from the plant) which is circulated across the faces of the plate. The principle is illustrated in fig. 3, which shows, at the left-hand end, a normal electrode plate, E. All elements between this plate and the first intermediate plate P_1 are bolted together as a single detachable unit. The adjoining pack commences with the second intermediate plate P_2.

The rather unusual shape indicated for the elements in fig. 3 was adopted so that a staggered arrangement of membrane packs could be made without interference occurring between the inlet and outlet piping of adjoining packs. In proceeding to the design of a large plant, in which thick end and intermediate plates can be used, a rectangular form with liquid introduction and removal at the sides of the plates has been adopted (fig. 5).

The membrane pack, bounded by intermediate plates, may therefore be regarded as a single hydraulic unit, whereas each entire press forms the electrical unit in the

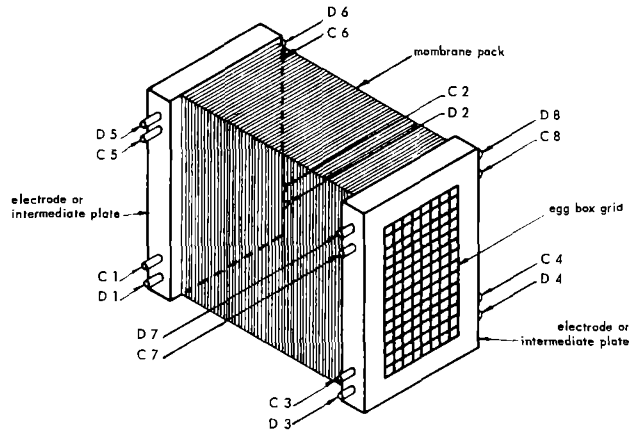

FIG. 5. Membrane pack.

demineralization plant. The maximum permissible terminal voltage (which may be determined by considerations of insulation, safety and availability) governs the number of packs of a given size which are placed between a pair of electrodes. It may be noted that the intermediate plate principle can also be applied to the introduction of more than one pair of electrodes into a press, the entire assembly being clamped by means of a single sealing gear (e.g. hydraulic ram system) (fig. 6). This method, using "intermediate electrodes", leads to a saving in sealing gear and press frame systems, and therefore of piping and space.

Assuming the general constructional principles outlined above, the values of such parameters as the number of stages in a multistage plant, the number of cell pairs per membrane pack, and the number of packs per press, may be arrived at by several methods, one of which is indicated in what follows.

Number of stages and current passed in each stage. Suppose a cost estimate to have shown operation to be most economic at a mean current density of $\bar{i}$, and suppose the cell design to be such that a total of N cells is necessary to achieve the desired desalting effect at this mean current. If the total flow of purified water is to be F_D, and the flow cross-section of each cell is a, then the dialysate velocity v in a plant of n equal stages is $\frac{F_D n}{N a}$. If the stages are operated in such a way that equal depolarization velocities prevail in each (see later), the value of this velocity, v_{crit}, is then obtained from an experimental k value by the application of equation (6) using the current $\bar{i}$ and the inlet and outlet dialysate concentrations applicable to the whole plant.

The number of stages, n, must then be such that

$$v_{crit} < \frac{F_D n}{N a} \qquad (7)$$

The condition of equal depolarization velocities in all stages of a multistage plant is highly desirable in ensuring that the same "safety margin" exists in each stage. The distribution of the mean total current, $\bar{i}$, over the stages that lead to equal depolarization velocities in each stage may, with some assumptions, one of which being that equation (6) is obeyed, be shown to be that which gives a constant *fraction* of desalting in each stage.

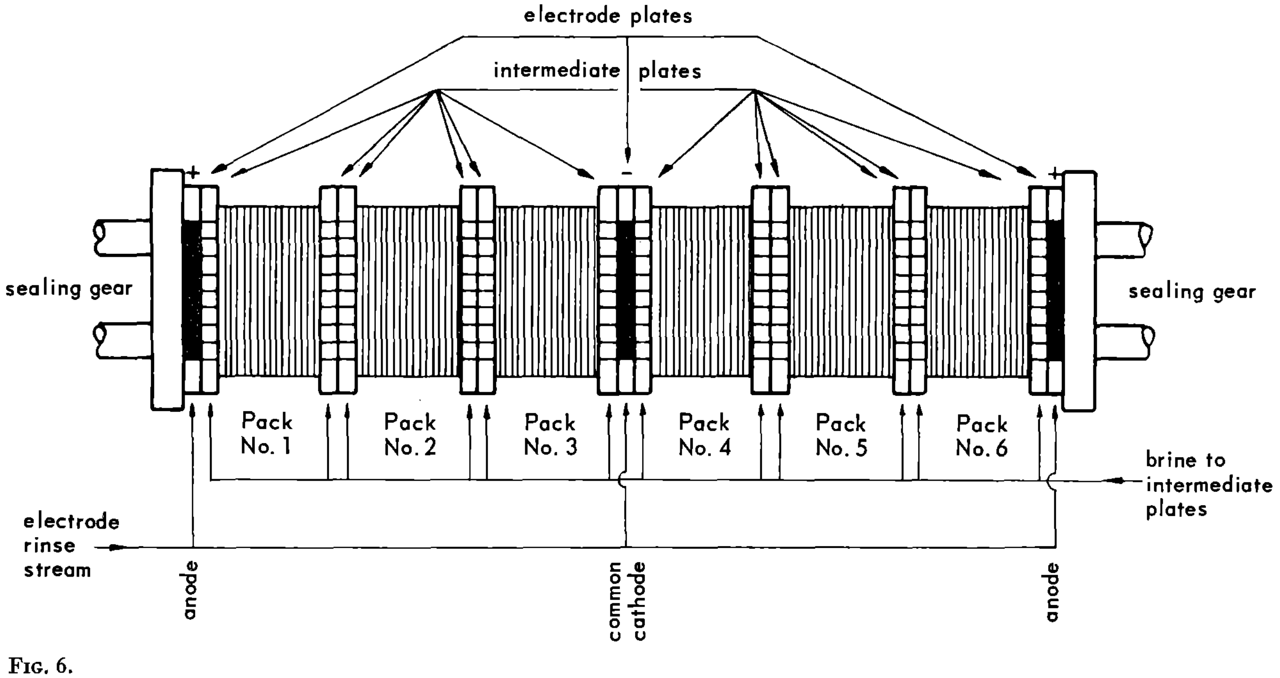

FIG. 6.

Number of cell pairs per membrane pack. Probably the most important limiting condition in this case is the maximum conduit velocity above which noticeable maldistribution of dialysate sets in. Either a maximum number of cell pairs can be stipulated on a consideration of maintenance and handling, e.g. 100 cell pairs, and the conduit dimensions chosen according to the maximum allowable velocity, or the matter can be approached from the reverse direction.

It is not possible to indicate a maximum permissible conduit velocity, as this is a function of the hydrodynamic nature of the entire membrane assembly. Thus, if high flow resistance exists in the membrane cells, a relatively large conduit pressure loss can be tolerated without significant maldistribution occurring. Quite empirically, it has been found with the intermembrane spacer apparatus (which is characterized by relatively small pressure loss) that maximum conduit velocities above about 75 cm./sec. are inadvisable.

Number of membrane packs per pair of electrodes. This is likely to be governed by the maximum permissible terminal voltage. If the cell resistances are known as a function of concentration, the voltage drop per pack, and hence the maximum number of packs per electrode pair, follow from the current densities chosen as indicated above.

It is on the above basis that the design of, and operating conditions for, the large-scale (450 $m.^3/hr.$) brack water demineralization plant at present being erected in South Africa were chosen. The available area of a single membrane is about 9,800 $cm.^2$, the breadth 70 cm. and the membrane spacing 0.85 mm. (it may be mentioned that the membrane size was determined essentially by a consideration of the largest membrane that could be manufactured reliably). Each pack is to contain 100 cell pairs (200 membranes) and five packs will be used per electrode pair. Using the principle of fig. 6, two such sets of five packs will be arranged in each concrete press frame, sealing being obtained by means of hydraulic rams. Each of the two desalting stages comprises four such presses.

MATERIALS OF CONSTRUCTION

Plates

The electrode end-plates and intermediate plates (if used) must be non-corrosive, dimensionally stable and capable of a certain amount of working (e.g. thread cutting). We have tried steel-backed gear bakelite, polyvinylchloride-coated steel, high-density polythene, cast glass-fibre reinforced epoxide and polyester resins, "Perspex" (polymethyl methacrylate) and resin-impregnated wood. The first two materials have the disadvantage that it is difficult to fabricate the various inlet and outlet holes with a perfect coverage of the metal at all points. High density polythene proved to have insufficient dimensional stability for the purpose. The glass-fibre reinforced resins, especially the epoxide resin, were highly satisfactory in moderate sizes (largest dimension about 75 cm.), but in the casting of very large plates it was difficult to obtain an even surface free of blow-holes. The machining of these materials, although possible, is expensive. "Perspex" seems highly suitable, but it is expensive in large sections. Phenol-formaldehyde resin-impregnated wood shows promise as an inexpensive material for the construction of large end and intermediate plates. It is important to use wood having a resin uptake of the order of 70 per cent. After fabrication, such plates are coated with an epoxide resin varnish so as further to reduce water penetration.

Gaskets

The gaskets are required to provide a seal, sealing being required over a greater or lesser area depending on whether the gasket is or is not integral with the liquid distribution system. In either case, a high degree of dimensional stability is important. The two requirements, ease of sealing and dimensional stability, conflict, and, whereas most workers have used plastic gaskets at a low sealing pressure, we have preferred to use a rubber-asbestos steam-jointing sheet material ("Klingerit") which has the property of swelling slightly in contact with salt waters. This material is relatively incompressible; a membrane pack generally leaks appreciably to atmosphere after its initial assembly although a high sealing pressure is applied. After a few hours, the leak ceases completely. If the clamping mechanism is rigid (i.e., not hydraulic) the sealing pressure remains at a high value, in contrast to the loss in sealing pressure due to cold flow which is the characteristic of some plastic materials. These rubber-asbestos gaskets can be re-used indefinitely.

Electrodes

There is little difficulty concerning material for the cathode, except that, if regular polarity reversal is to be used for the control of scaling in electrodialysis plant, both electrodes must be capable of functioning in either capacity. Otherwise, nickel and stainless steel cathodes function well.

There is as yet no satisfactory inexpensive, or even fairly expensive, permanent anode material. Materials that have been used include lead, magnetite, platinum coated tantalum and graphite. Magnetite anodes are heavy, expensive and not permanent, and their use is undesirable in plants in which the anode rinse product is used for re-acidulation of the filtered water, because traces of iron in solution have a deleterious effect on the cation-permeable membranes. Graphite electrodes, which are free from this objection, seem to be the best suited to plants in which polarity reversal is applied, although they are subject to corrosion in waters in which the main anion present is sulphate. Their durability can be improved by treatments which reduce the porosity, e.g. resin impregnation.

ACKNOWLEDGEMENT

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RÉSUMÉ

Construction d'une installation pour la déminéralisation de l'eau saline par électrodialyse (B. A. Cooke, O. B. Volckman et J. R. Wilson)

Les auteurs examinent les principaux problèmes que pose la construction d'une installation de déminéralisation de l'eau saline par électrodialyse — à savoir les pertes par effet Joule et la polarisation. Ils décrivent successivement les deux principales solutions pratiques données à ces problèmes et en comparent les avantages. Ils fournissent des indications assez détaillées sur la construction d'un de ces types d'appareils — celui qui utilise une feuille plastique ondulée et perforée pour maintenir les membranes — et notamment sur son emploi pour dessaler les eaux saumâtres en Afrique du Sud.

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FIELD OPERATION OF ELECTRIC MEMBRANE EQUIPMENT FOR WATER DESALTING

by
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The first commercial plant for the production of potable water from a saline source using electrodialysis and ion exchange membranes was put into operation by Ionics, Incorporated, in June 1954. In the period of over four years since that time, Ionics has installed and is installing for customers an additional 31 water demineralizers. Of this total of 32 installations, 25 are for the purpose of producing water for human consumption from a variety of saline sources. The remaining seven units have been used primarily to obtain data concerning the performance of the process and its components under a variety of operating conditions. Three are under test at the present time. This report on field operation refers primarily to those 16 plants operating or about to be started up in the Middle East.

To our knowledge, the Ionics electric membrane process is the only "new" process—that is, a process to emerge from the laboratory or pilot stage since World War II—which is now supplying fresh water for use. By early next year, between 30,000 and 40,000 people will get their entire drinking and culinary water supply from Ionics units situated in the United States of America, on the Texas Towers in the Atlantic Ocean, in Bahrain, Kuwait, United Arab Republic (Region of Egypt), and other parts of the Middle East. In addition to direct culinary or drinking requirements, Ionics plants are supplying make-up to a large central station steam power plant and water for ice manufacture and soft drink bottling.

The purpose of this paper is to discuss the field experience obtained to date by Ionics, Incorporated, in the operation of its commercial membrane demineralizers. Following a brief review of the nature of the process itself, the field operating problems which have been encountered are reported, together with their solutions. Finally, the operating plants and those to be installed in the near future are listed and described. Pertinent information is given for each plant.

ION EXCHANGE MEMBRANE "STACK"

Ion exchange membranes are thin sheets of either cation or anion exchange resins. The membranes' properties relevant to water purification are their high electrical conductivity, low permeability to the passage of water, and high selectivity to cations and anions [5, 10].[1] The name "ion-exchange" membranes refers merely to the composition of the membranes themselves, and not to the actual process, since in electrodialysis operations there is no exchange of ions between a membrane and a given solution in the same sense that occurs in the conventional use of granular ion exchange materials. Ion exchange membranes are thus better referred to as ion transfer membranes and electric membranes.

Fig. 1 is the usual schematic diagram of the configuration of a multiple compartment membrane cell of the type used in the demineralization of saline waters by electrodialysis. Electrodialysis cells for this type of application consist of a large number of alternating anion and cation transfer membranes separated from each other by electrically resistive gaskets, or spacers. These spacers have some type of flow path cut in them to allow (a) solution to flow parallel to the membrane faces in the cells formed by the membranes and the spacer channels, and (b) the electric current to flow perpendicular to the membranes and solution passages. At each end of this "stack" of membranes and spacers are located electrodes connected to a source of direct current. Two inlet streams and two outlet streams are manifolded to the alternate compartments, or cells, formed by each pair of membranes and its separating gasket. A saline water feed is thus converted into a potable demineralized stream and a concentrated brine stream.

The design principles, present-day economics, and membrane properties have been presented in detail by others [6, 8, 9]. It will be sufficient in this introduction to a report on the field operating experience to state that in

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[1] The figures in brackets refer to the bibliography on page 370.

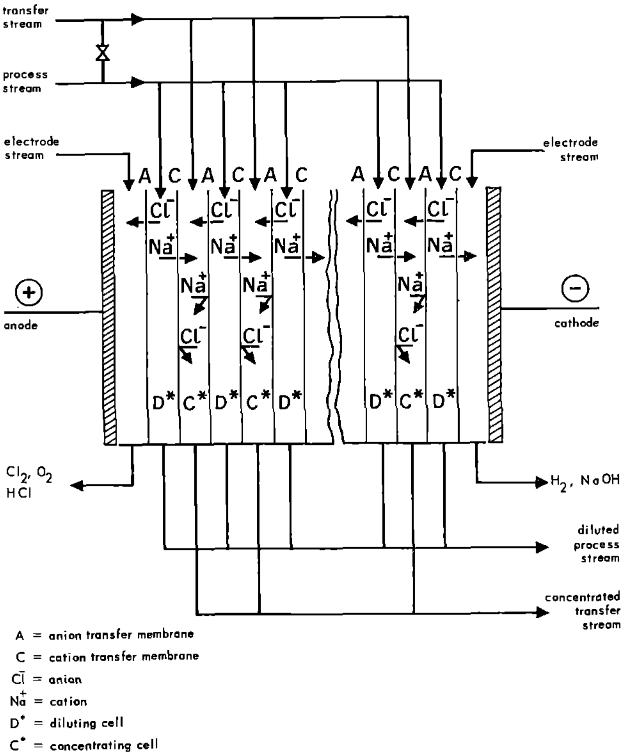

FIG. 1. Multi-membrane concentrating and diluting cells.

each membrane stack described above a direct current is passed under an applied DC voltage. The membrane stack resistance, voltage and current follow Ohm's Law, with the resistance being determined by the ionic concentration in the diluting and concentrating compartments and the membrane resistance itself. The total number of ampere-hours required for a given demineralization and the rate of salt removal follow Faraday's Law. Therefore, in the operation of a standard 150 cell-pair membrane stack as described above, doubling the stack current and thereby the current density for a given feed rate will double the demineralization capacity of the membrane stack. The effect of increasing the current density for a given demineralization will be to lower the installed cost of the plant and also to increase the energy consumption per volume of treated water. The economic balance between these two factors partly determines the current density which is employed.

POLARIZATION

In addition, there are physical and chemical limitations affecting the magnitude of the current density that can be applied to a membrane stack. In the many applications of electrodialysis investigated by this laboratory to date, an important factor limiting the applied current density (and hence equipment capacity) has been that of polarization. In a recent publication, Rosenberg and Tirrell discuss polarization in membrane systems [11].

While practically all of the ions are transported across the membranes in electrodialysis by electrical transport, only about one-half of the ions arriving at the membrane interface from the bulk of the solution are carried by electric transport; the remainder arrive at the membrane interface as a result of diffusion. As the ions are transferred from the diluting cell through the membrane, the concentration of electrolyte in the diluting cell in the region immediately adjacent to the membrane surface becomes depleted, and the driving force for diffusional mass transfer increases. As the current density is increased, this region, or transfer film, next to the membrane becomes so depleted in electrolyte that the electrical resistance rises sharply and transfer of hydrogen and hydroxyl ions (due to dissociation of water) becomes appreciable. "Polarization" thus occurs gradually as the current density applied to a membrane cell is increased. Polarization, as discussed here, only occurs in the diluting compartments, since it is from these cells that transfer and depletion is taking place. When polarization becomes pronounced at an anion transfer membrane, hydroxyl ions are transferred into the concentrating stream, making it basic; hydrogen ions remaining in the diluting cell from the dissociated water cause a decrease in the *p*H of the diluting stream. Polarization of cation transfer membranes results in transfer of hydrogen ion into the concentrating stream, thus decreasing its *p*H and increasing the *p*H of the diluting stream.

Operation at current densities sufficient to cause significant polarization can cause several inefficiencies. The electrical resistance of the cell-pair increases so that the energy consumption increases. The current efficiency decreases, since the transfer of hydrogen and hydroxyl ions is not the desired object of the operation.

In addition to these inefficiencies, serious operational difficulties can be experienced as a result of the *p*H changes which accompany polarization. The presence of salts which form basic precipitates can cause severe scaling in and on the membranes under polarizing conditions. Care must be taken in treating solutions containing calcium, magnesium, and bicarbonate ions to avoid the formation of calcium carbonate and magnesium hydroxide precipitates. The formation of calcium carbonate precipitate in the concentrating cells during the demineralization of naturally saline waters will be discussed below.

Careful adjustment of the applied current densities and *p*H of the feed solutions has been effective in eliminating calcium carbonate precipitation.

The current density at which the effects of polarization become significant in an electrodialysis process is referred to as the limiting current density. The experimental criteria of polarization can be an increase in the electrical resistance per cell-pair, a decrease in the differential current efficiency, a change in solution *p*H of definite magnitude, or a definite concentration of hydrogen or hydroxyl transferred through the membranes.

Since polarization phenomena become more acute as the transfer film adjacent to the membrane surfaces becomes depleted in electrolyte, increasing the rate of diffusional processes that promote the transfer of electrolyte from the bulk of the stream to the membrane interface raises the limiting values of the polarization parameter. Avoidance of stagnant areas in the cells and increased mixing of the solution across the cells are beneficial. Use of a well-defined flow path has been found to be effective in increasing the limiting current densities, as has the use of increased velocities [4].

Limiting current densities for ion exchange membrane systems have been found to be directly proportional to the concentration of electrolyte in the diluting solution. For maximum equipment capacity, the voltage applied to a stack is adjusted until the ratio of current density to concentration of the diluting stream safely approaches a polarization value at some point along the flow path of each cell-pair (it is assumed that conditions in all cell-pairs in the stack are similar, which is normally the case). The safety factor required and the limiting value should be evaluated for each natural water to be treated.

SCALING

The most serious operational difficulty caused by polarization or by supersaturation is the formation of calcium carbonate precipitates in and on the concentrating face of the anion transfer membranes. The formation of scale in electrodialysis units is undesirable since the electrical resistance of the stack rises sharply as this scale is deposited. In addition, continued formation of scale within a membrane unit can result in loss of ion exchange resin from the surface and a gradual physical deterioration of the membranes. Accumulation of the scale in the flow passages can also result in the bowing and final rupture of the membranes bounding the flow path.

The majority of brackish waters encountered are supersaturated in calcium carbonate and many are close to being saturated in calcium sulphate. Since no significant heating of the water is involved during the demineralization process, one might expect that no deposition of scale would result. Operation on brackish waters has shown that no scaling normally occurs on the membrane surfaces bounding the diluting stream; however, calcium carbonate scale does form on the side of the anion membrane facing the concentrating stream. No scaling of the cation membrane has been experienced. Electrodialysis results in a rise in the concentration in the concentrating stream; and in addition to precipitation from a supersaturated solution, the transfer of hydroxyl ions through the anion membrane due to polarization can cause a shift in the bicarbonate-carbonate ratio present in the water such that the precipitation of calcium carbonate results.

The solution to the calcium carbonate scaling problem has been simply accomplished by the continuous feeding of sulphuric (or other) acid to the blowdown stream to reduce the concentration of bicarbonate ions. No change in *p*H of the diluting stream occurs, and a *p*H change of about 0.5 units occurs on the concentrating stream. Approximately 1 lb. of concentrated sulphuric acid per 1,000 gallons of demineralized water is the average acid consumption. Costwise, this amounts to 1–2 cents per 1,000 gallons, which is a negligible cost factor. Not only does the addition of acid in this manner prevent scaling, but it also effectively removes scale from plants even after weeks of accumulation. The Langelier saturation index for calcium carbonate can be used in estimating the quantity of acid required for a particular water so as to obtain non-scaling conditions [13].

Calcium sulphate scaling has been less serious and can be completely controlled by providing adequate blowdown so as to avoid any considerable degree of supersaturation in the concentrating stream. Sequestering agents have been found to be helpful in reducing the blowdown (the volume of concentrating stream sent to waste per unit of product water) required to prevent formation of calcium sulphate scale. When calcium sulphate precipitation does occur, it forms as a non-adherent material within the flow passages of the concentrating stream and is easily removed by flushing.

SURFACE EXHAUSTION

Another phenomenon which has presented operational problems in the field is surface exhaustion. Its symptoms are an increase in membrane stack resistance and simultaneously a lowering of the polarization point. Its effect was to lower the stack current and therefore the production rate. It is important to note that this problem has arisen at only three of all the plants operating and that this resistance increase has *not* been due to scaling. It is also important to note that this surface exhaustion is associated with the anion membrane only. This phenomenon is quite unlike the other problems mentioned above or later in this paper, such as calcium carbonate or iron sulphide scaling, where the deposition of slime or scale is clearly visible. This is a case where the anion membrane has become highly resistant to ion transfer in complete absence of scale or slime, in fact there is no change in the physical appearance of the membrane. Ionics has been successful in reactivating the surface of the anion membranes which have exhibited this exhaustion by physical and chemical means. For example, in the unit operated by the Kuwait Oil Company in Kuwait, the resistance of the anion membranes had recently increased to such an extent that the stack resistance had doubled, resulting in a production rate of only 2,000 imperial gallons per day instead of the normal 4,000 imperial gallons per day. By the proper physical and chemical treatment these anion membranes were reactivated and the plant is now operating at normal output. The exact cause of this surface exhaustion in the Kuwait plant is not known at this time, but further laboratory and field study will undoubtedly reveal its nature. The important consideration is that in the few isolated cases where anion membranes exhibit this surface exhaustion they can be quickly and easily reactivated in the field by unskilled labour at low cost, with the resultant effect of markedly extending anion membrane life.

PRETREATMENT REQUIRED ON FEED WATERS

Solids removal

Because of the fine passages provided for flow within the membrane stack, it is necessary to remove any significant amount of suspended solids from the feed water. Most suspended material or organic nature tends to adhere to the surface of the membranes, forming a slime. Deep well waters in general require no filtration; on occasion, silt or sand is entrained owing to the pumping action, and rapid sand filtration or settling is required.

For most surface waters where colloidal material is found in suspension, coagulation and sand filtration is required. If the concentration of material is low (< 20 ppm.), diatomite earth filtration is satisfactory.

Bacterial growth

It was generally found that the membrane stacks serve as a breeding ground for many types of bacteria found in non-sterile water. No significant attempt has been made to isolate the types of bacteria that were involved. If the feedwater and membrane systems are initially free from bacteria, no build-up occurs. Large multiplications will occur in the membrane stack if bacteria are present in the feedwater. Prechlorination to maintain a residual in the product water has solved the problem. One situation developed recently in one of the Middle East plants where symptoms of surface exhaustion became evident after an extended period of shut-down. Membranes from this plant were also reactivated by the same physical and chemical means employed in the Kuwait plant case. Evidence to date indicates that the cause of the surface exhaustion was bacterial in nature, but further work is necessary to prove this conclusively.

Iron fouling

Waters containing 0.3 ppm. of iron or less have been successfully treated for thousands of hours without pretreatment. Waters containing 1.0 ppm. of iron or more deposit a brown slime on the surfaces of the membranes, which eventually affects the performance of the system. The removal of the iron by oxidation (aeration or direct chlorination) and filtration is recommended if the iron concentration is greater than 0.3 ppm.

Iron-hydrogen sulphide fouling

In the Middle East area, waters containing large amounts of iron (5 ppm.) and hydrogen sulphide (60 ppm.) were encountered. Much of the material was in the form of suspended iron sulphide; the untreated water deposited an adherent black glossy film on the surface of the membranes which could be removed only by chemical treatment. Many membranes became brittle and ruptured under these conditions. It was necessary to remove this material from the feed water; this was accomplished by direct chlorination followed by filtration. A large installation would employ aeration-settling to reduce the chlorination-filtration load.

MEMBRANE STABILITY

In the absence of long-term field experience, the most hazardous factor to predict in considering the use of electrodialysis for the demineralization of saline waters was the stability of any given type of membrane. Faulty operation of electric membrane equipment can result in serious physical deterioration of membranes. For example, under conditions of severe polarization with waters containing calcium and bicarbonate, membranes can scale quickly so that the electrical resistance rises quickly and finally resin is lost from the membrane surfaces until leakage results between concentrating and diluting streams. Like any other piece of industrial equipment, membranes can be damaged.

Probably the most important information (next to the fact that potable water is produced) obtained from the operation of electric membrane equipment in the field for the production of potable water is that concerning membrane stability under routine long-term operation in which reasonable care is taken to protect the equipment. Because the life of membranes is closely related to the treatment to which they are exposed, membrane stability will be discussed in the following sections dealing with field experience in the operation of electrodialysis water demineralizers.

In summary, though, the experience with membrane stability has been encouraging where the ratio of current density to solution normality has been controlled, and where *p*H adjustment of the concentrating stream has been carried out to avoid scaling conditions.

REVIEW OF FIELD EXPERIENCE IN OPERATION OF ELECTRODIALYSIS WATER DEMINERALIZERS

As of 1 October 1958, there were ten Ionics water demineralizing plants in operation in the Middle East, producing good quality drinking water from contaminated sources, and six other plants were either in the process of construction or about to be started up. A brief description of each installation is included in this paper; and Table 1 summarizes the conditions under which each is operating.

Plant no. 1 produces drinking water for a mining camp of 150–200 men. Operation of this automatically controlled unit, for the most part, has been unattended.

Plant no. 2 is located in the Middle East area. It was initially a mobile unit supplying fresh water for an

TABLE 1

Plant no.	Operating organization and location	Date of start-up	Type of plant[1]	Source of water	Purpose of plant[2]	Total hours operation[3]	Feed tds. ppm.	Production tds. ppm.	Production rate gph.	Total energy consumption kWh/k. gal.
1	—[4]	June 1954	B	Well	P	21 000	2 400	1 000	100	20
2	—[4]	Oct. 1954	B	Well	P	15 000	2 000	500	200	15
3	Bahrain Petroleum Co., Bahrain	June 1955	C	Well	P	27 600	3 150	400	1 200	16
	Revised larger plant	Sept. 1957	C	Well	P	9 300	3 150	400	3 600	16
4	—[4]	June 1956	B	Well	P	500	1 000–8 000	500	100–800	5–35
5	Yateem Brothers, Bahrain	June 1956	B	Well	P	17 000	3 100	200	200	15
6	Kuwait Oil Co., Kuwait	June 1956	B	Well	P	9 600	4 300	500	210	25
7	A. Algosaibi Bros., Bahrain	May 1957	B	Well	P	9 000	3 200	350	200	18
8	—[4]	April 1958	C	Well	P	1 500	1 800	300	1 200	14
9	Getty Oil Co., Kuwait	Pending	B	Well	P	0	4 000	500	700	20
10	Oasis Oil Co., Libya	Pending	B	Well	P	0	Varies for this portable unit			
11	—[4]	June 1958	B	Well	P	1 000	1 000–8 000	500	100–800	5–35
12	—[4]	Nov. 1958	B	Persian Gulf	P	0	43 000	500	30	220
13	ICA Tobruk, Libya	Jan. 1958	B	Well	P	0	4 000	500	230	20
14	—[4]	June 1958	B	Well	X	1 000	Varies for this portable unit			
15	—[4]	Nov. 1958	B	Well	P	0	2 300	500	660	12
16	—[4]	Dec. 1958	B	Well	P	0	2 600	500	300	13

1. B = batch; C = continuous.
2. X = experimental; P = production.
3. Estimated to 1 October 1958.
4. Customers prefer non-disclosure.

exploration crew of approximately 30 men. Brackish feed waters were obtained from a number of deep wells whose solids content varied considerably. In addition, large quantities of hydrogen sulphide and dissolved and suspended iron were encountered. To take advantage of the plant's substantial output, it was subsequently located permanently at one of the more desirable well-heads, to serve as a central supply source for a base community and various exploration activities. The capacity of the plant exceeds the demand in the area, so that the equipment is operated only when necessary to refill a storage tank. Start-up and shut-down of an electric membrane unit is a simple matter and is done quickly.

Plant no. 3 was the third continuous plant constructed by Ionics and the first continuous type plant installed in the Middle East. It embodied the improvements made possible by the study of the operation of previous continuous plants in the United States for the Department of Interior and the Texas Electric Service Company. It was Ionics' first continuous type commercial plant and has achieved a remarkable record of producing at rated output for 98 per cent of the time since its start-up in 1955. The output of the original plant (approximately 30,000 gallons per day) supplied approximately 60 per cent of the fresh water requirements for the community of Awali, containing several thousand people in a hot, arid section of the Middle East. Operation was so satisfactory that the plant has been expanded to three times its original capacity. Initial operation of the expanded plant began in September 1957. The expanded plant will supply the entire potable water requirement for the refinery, the community of Awali, and for the large native working force who carry jugs of the potable water home each day. The original plant contained five stacks of 150 cell-pairs operating in series to produce about 28,000 gallons per day of potable water. The enlarged plant contains three such lines of five stacks each. The feed water comes from an iron piping system, but iron deposition in the membrane system has not been a serious problem. The feed water, containing about 0.3 ppm. iron, is passed through sand filters (which are backwashed about once a year) producing a residual iron content of about 0.1 ppm.

Without regard to cause, over-all membrane replacement in the original plant has averaged about one-third of the 1,500 installed membranes per year.

A large fraction of this number were cation transfer membranes which became ruptured following deterioration of the glass cloth backing contained in the membranes for support. For example, a total of 285 of this type of membrane were replaced in the first year of operation; as these were removed, they were replaced with cation transfer membranes having a more stable glass backing. In the first 15 months' operation following this change, only 66 of these new membranes required replacement.

Initial operation of this plant took place at a time before the effectiveness of *p*H adjustment of the concentrating stream had been established, so that serious scaling of the membranes occurred in the first 2 to 3 months of operation. Following adoption of *p*H adjustment at that time, scaling was halted and the scale was removed gradually from the membranes. Deposition of iron slimes has been observed in both concentrating and diluting cells. Periodic treatment (once a month) with a sequestering agent has been effective in removing the iron slime.

A number of the anion transfer membranes that had been removed from this plant and replaced were still suitable for use following removal of adherent scale by a mild acid treatment. Some of the membranes have lost sufficient resin (apparently due to scaling) that further use is not justifiable in a commercial plant.

Despite the problems of scaling and rupturing during the initial period of operation, the previously estimated average membrane life of about three years was substantiated. Recent verbal reports on the first year's operation of the revised larger plant indicate that the membrane replacement rate has been as low as 10 per cent per year.

Maintenance labour on Plant no. 3 has averaged about 30 hours per stack per year, of which about two-thirds has been spent in membrane inspection, cleaning, and replacement, and the other one-third, in maintenance of other components. The operating labour assigned to any piece of equipment is frequently as much a matter of management philosophy as actual demand. The practice of the company owning Plant no. 3 is to assign at least one full-time native operator to each different process in the refinery. Over the first two and one-third years, one full-time operator was assigned to the demineralizer, and he took and recorded readings of all meters and gauges once an hour for that entire period besides keeping the area swept clean. His principal useful function (since a foreman stops in once a day to read the meters and check on performance) was that of diluting the acid required by the electrodes and *p*H adjustment; this task required an average of about 1 ½ man-hours per day. The new plant is three times as large as the original plant, and two full-time operators are assigned to the area.

Plants no. 4 and 11 are standard model Ionics demineralizers sold to the army of a Middle Eastern nation following a field demonstration. Owing to the recent unrest that has developed in the Middle East, these plants have been operated only intermittently.

Plant no. 5 is a standard model Ionics demineralizer sold to an enterprising Arab merchant in Bahrain. The output from this unit has been used for ice manufacture and bottled water. This plant has already paid for itself by savings in operating cost as compared with those of the distillation plant that this customer had been operating for several years previously. The owner of the unit reports that his customers prefer the taste of the membrane-demineralized water to that formerly produced by his still.

Demand for water in Bahrain drops off somewhat during the winter months so that it has been necessary to operate the plant only about 90 per cent of the time since its installation. Over the period of operation, maintenance on the entire one-stack plant has been about 50 hours per year, even including time spent in painting the equipment and surrounding area. The stack has been taken apart a few times to replace membranes, principally damaged by precipitate build-up caused by blocked cells. A total of 30 out of 300 membranes (10 per cent) have been replaced in 27 months of operation. Operating labour has averaged about two man-hours per day, which is largely spent in preparing acid for feed to the unit. Other than occasional checks by the foreman of the associated ice plant, the unit is left unattended.

A recent inspection of the entire stack by an Ionics engineer while he was in Bahrain revealed no evidence of scale in the membranes and no physical weakening of either the anion or cation transfer membranes, and there has been no increase in the electrical resistance of the stack or decrease in production rate at the stated energy consumption. Since the feed water to the plant is the same as that for Plant no. 3 (see Table 1), the absence of scale and resistance rise may either be attributable to better *p*H adjustment in Plant no. 3 or to the cycling action the membranes receive in batch units. Since the concentration of the diluting stream is continually changing in a batch recycle unit, the ionic environment of the membranes is continually being changed.

Plant no. 6 is located in Kuwait in the Persian Gulf. This unit was mounted on a single skid to permit easy transportation by truck or trailer, although it has been primarily located in an advanced oil exploration base since its start-up in June 1957. This plant operated from June 1957 to May 1958 without serious operating problems; and the plant operated at rated capacity over 90 per cent of the time. From May until September the stack resistance increased markedly, resulting in greatly reduced output during this period. As explained above, this resistance increase of the anion membranes occurred in the absence of scaling or slime formation and the problem has been termed surface exhaustion. As a result of studies at the Ionics laboratory, certain physical and chemical treatments were performed on these anions in the field. The reactivated membranes were reinstalled and the plant is now operating at rated capacity.

Plant no. 7 is owned by the Canada Dry bottler on the island of Bahrain. It produces the good quality water required in soft drink bottling. This plant was started up in June 1957, and has since then produced sufficient water for the entire bottling operation. During May 1958, the symptoms of surface exhaustion became evident. Membranes from this plant have also been successfully reactivated by simple physical and chemical methods. Membrane replacement in 15 months of operation has been less than 5 per cent, which again is far below the estimated three-year life.

Plant no. 8 was installed in March 1958 for a well-known Middle Eastern oil company to provide drinking water for a community of about a thousand people. This is a continuous-type unit containing three stacks and producing about 28,000 gallons per day from a brackish source. After a few months of operation, it was shut down for lack of spare parts for the pump. On restarting the plant after a three-week shut-down period, the stacks showed high resistance and other symptoms of surface exhaustion. As mentioned above, the existing data indicate the cause to be of a bacterial nature but further tests are necessary to prove this conclusively. Membranes from this plant have been reactivated by the same procedures as those used in Plants no. 6 and 7. It is interesting to note that this surface exhaustion problem has occurred in only 3 plants out of a total of 26 plants operating in various areas throughout the world.

Plant no. 9 has been delivered and will be started in the near future in the Kuwait Neutral Zone. It will serve as a potable water-producing facility for an oil company community.

Plant no. 10 is a small, portable unit especially designed for desert exploration camps. This unit will produce about 700 gallons per day on an average 3,000 ppm. brackish water and will be used by the Oasis Oil Company to supply drinking and cooking water for small exploration and drilling groups.

Plant no. 12 will be installed in the near future for the personal use of a prominent member of a Middle Eastern government. The unit will produce potable water from the highly saline Persian Gulf.

Plant no. 13 is a standard model demineralizer which will be installed in a hospital in Tobruk. It will be operated by the ICA and will supply drinking water and other water requirements of the hospital.

Plant no. 14 is a small portable unit which has been operated by a well-known Middle Eastern oil company since June 1958. The purpose of the unit is not only to supply drinking water to advanced exploration parties, but also to act as a test unit at locations where well water is difficult to demineralize by any method. The special cases include feed waters saturated in calcium sulphate and containing high iron and sulphide concentrations. To date this unit has operated exceptionally well.

Plant no. 15 will supply drinking water to a military group in a desert area of the Middle East.

Plant no. 16 is a completely mobile demineralizer for exploration and drilling camps, and will be started up in the near future for the same Middle Eastern oil company that operates Plants no. 2, 8 and 14.

FACTORS DETERMINING MEMBRANE REPLACEMENT COSTS

Whereas the investment in plant facilities and the power cost can be estimated reliably after short-term tests, the very significant operating costs arising from membrane replacements can only be determined from field data such as that presented above. Membrane replacement costs depend upon initial cost, average life and permissible current per square foot of "membrane cell pair" (one square foot of cation membrane plus one square foot of anion membrane). Further, the nature of membrane deterioration has a bearing on operating and maintenance labour, on on-stream time or stand-by equipment and on plant capacity or power consumption.

A number of economic projections of the production of potable water by Ionics electrodialysis have been reported [1, 6, 8, 12, 13] and at least two extensive comparisons of various alternate desalting techniques [2, 3] have been made. These surveys have indicated that electrodialysis appears economically superior to existing processes for the treatment of brackish waters, and offers considerable long-range economic potential for the desalting of sea water. The reader is referred to the above references for details of cost projections and comparisons.

The experience now obtained on the long-term operation of Ionics commercial electrodialysis equipment in the field provides the first basis of actual cost. As has been shown above, valid estimates of cost and performance require experience of several years of actual commercial field operation on different waters. Only when other membranes and other new processes have been tested with proper operation for similar periods will a true comparison become possible.

A brief summary of the conclusions of previous economic comparisons is presented for completeness. When used to desalt water, electrodialysis and ion exchange operate on the basis of removal of the salt from the water to produce a demineralized product. Most of the other processes used today (such as distillation) or proposed for future development operate by removing the water from the salt solution. Thus, ion exchange offers the cheapest method of removing salts from waters having very low salt content. The cost of producing desalted water by ion exchange, however, rises rapidly as the salt content of the raw water increases due to the increase in the resin inventory required.

At the present time, electrodialysis treats brackish waters more cheaply than other processes. In very dilute solutions, the electrical resistance of the solution is high and the allowable current density is low, so that the costs of electrodialysis exceed those of ion exchange. In brackish waters, however, the solutions are more conductive and higher current densities can be utilized without polarization. Thus, for raw waters in the range from about 1,000 ppm. to about 10,000–15,000 ppm., the combined operating costs of electrodialysis (including amortization) are less than for ion exchange or for distillation, and the investment is also less. It is also true that in most cases distillation processes are inoperative on brackish well water containing large quantities of calcium, sulphate, and bicarbonate.

In sea water, considerable salts are present so that those processes that remove the salt from the water become relatively attractive. The large amount of salt to be removed causes the production rate, in terms of 1,000 gal. product/sq.ft./day, of electrodialysis equipment to be low (with present membranes, limiting current densities cannot be employed with sea water without overheating of the membranes), and the resistance of the membranes accounts for a considerable fraction of the electrical consumption. Today both the investment and energy costs of electrodialysis equipment for treating sea water are usually greater than for vapour compression distillation. Selection of Ionics electrodialysis equipment for treating sea water today depends upon some of its special features such as low operating and maintenance labour or lack of noise.

The development of ion transfer membranes of considerably lower resistance than those commercially available today offers the promise of economically competitive desalting of sea water by electrodialysis. Such membranes would allow the safe use of high current densities (to increase equipment capacity) without excessive energy consumption.

RÉSUMÉ

Utilisation pratique des appareils électriques à membranes pour le dessalage de l'eau (J. H. Powell et E. M. Guild)

Depuis plus de quatre ans, des appareils électriques à membranes tels qu'on en trouve dans le commerce fournissent de l'eau potable en diverses régions du monde. Dans le seul Moyen-Orient, dix installations de ce genre fonctionnent déjà et six autres vont être mises prochainement en service. L'expérience ainsi acquise montre que, pour la déminéralisation de l'eau saumâtre, le matériel d'électrodialyse est efficace et très économique.

La principale source des difficultés qu'on rencontrait avec les premiers appareils mis en service était l'entartrage des membranes par le carbonate de calcium. Mais, en choisissant convenablement la tension du courant électrique utilisé et en corrigeant le *p*H du courant d'eau de concentration, on a réussi à maintenir ces appareils en fonctionnement de façon ininterrompue.

Dans un petit nombre de cas, de nouveaux problèmes ont surgi, tel celui de l'épuisement des surfaces; toutefois, la réactivation des membranes anodiques s'est révélée possible, et les membranes ont été remises en service.

En utilisant pratiquement ce matériel, on a constaté que la plupart des causes d'échec imputables aux membranes étaient d'ordre physique, et tenaient à une précipitation à l'intérieur des membranes ou à leur surface, qui provoquait la rupture. Les premiers rapports établis au sujet des membranes mises hors de service ont indiqué que celles-ci avaient duré trois ans environ. Par la suite, l'entartrage ayant été supprimé, on a constaté qu'elles pouvaient avoir une vie beaucoup plus longue.

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RECHERCHES AU MAROC SUR LA DÉMINÉRALISATION DES EAUX SALINES ET SAUMÂTRES PAR DISTILLATION SOLAIRE

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INTRODUCTION

Le Maroc, comme beaucoup de pays de la zone aride ou semi-aride, recèle pour une part des eaux souterraines saumâtres ou minéralisées au-delà des limites normales de potabilité. Une statistique basée sur 1000 analyses chimiques complètes a révélé:

50 % des eaux à salinité inférieure à 1000 mg/l[1];
47 % des eaux à salinité comprise entre 1000 et 3000 mg/l;
3 % des eaux à salinité supérieure à 3000 mg/l.

D'après les normes généralement admises de classification des eaux potables pour les humains, le Maroc possède donc 50 % d'eau souterraine de qualité médiocre, mauvaise, de potabilité momentanée ou non potable. Or les besoins pour la consommation de la population sont couverts, dans la proportion de 70 %, par les eaux souterraines.

Le pays se heurte donc à de sérieuses difficultés pour pourvoir à ses besoins avec des eaux de bonne qualité. Jusqu'ici, les villes et centres urbains ont pu être dotés d'eau de teneur inférieure à 1000 mg/l de résidu sec, grâce à de sérieuses études. Mais l'accroissement rapide de la population — et, partant, de ses besoins — conduira rapidement à l'utilisation des eaux saumâtres.

Déjà, des villes ou centres de la côte atlantique comme Safi, Agadir, Tamanar, Tarfaya, ou de la zone présaharienne, tels que Erfoud, Zagora, Bou Anane, etc., posent des problèmes difficiles.

Nous allons examiner:

1. Les divers types d'appareils construits au Maroc et expérimentés à Ksar-es-Souk entre 1952 et 1955;
2. Les résultats de l'exploitation contrôlée des appareils "Sétude" construits en Algérie et expérimentés à Oujda et Meknès à partir de 1956.

RÉALISATIONS "MAROC" ET RÉSULTATS

De 1952 à 1955, cinq spécimens d'appareils ont été conçus au Maroc et expérimentés (à l'exception de deux) à Ksar-es-Souk (Tafilalt). Ces spécimens se ramènent à deux types essentiels:

Type I: châssis métal ou bois, panneaux verre, cuve zinc;
Type II: entièrement en matière plastique, sans châssis.

Type I[2]

Constructeur: Société marocaine de distribution (SMD); année de fabrication: 1953; mise en service: avril 1953; prix de revient: 35000 FM par mètre carré.

Rendements. Les mesures de la variation du débit en vingt-quatre heures ont été effectuées au moyen d'un appareil enregistreur. Les résultats — où le débit en grammes est ramené à une surface de un mètre carré — sont donnés dans le tableau 1; ils sont traduits également sur graphique (fig. 2).

TABLEAU 1. Variation du débit en vingt-quatre heures (septembre 1954)

	Heure	Température	Débit
		°C	g/m²
Lever du soleil	6 h	25	
	7 h	30	2
	8 h	34	14
	9 h	37	58
	10 h	38	94
	11 h	38	197
	12 h	39	260
	13 h	39	288
	14 h	39	291
	15 h	39	298
	16 h	39	291
	17 h	38	233
	18 h	37	145
Coucher du soleil	19 h	35	66
	20 h	32	22
	21 h	30	6

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[1] Teneur en résidu sec à 180°.
[2] Voir fig. 1.

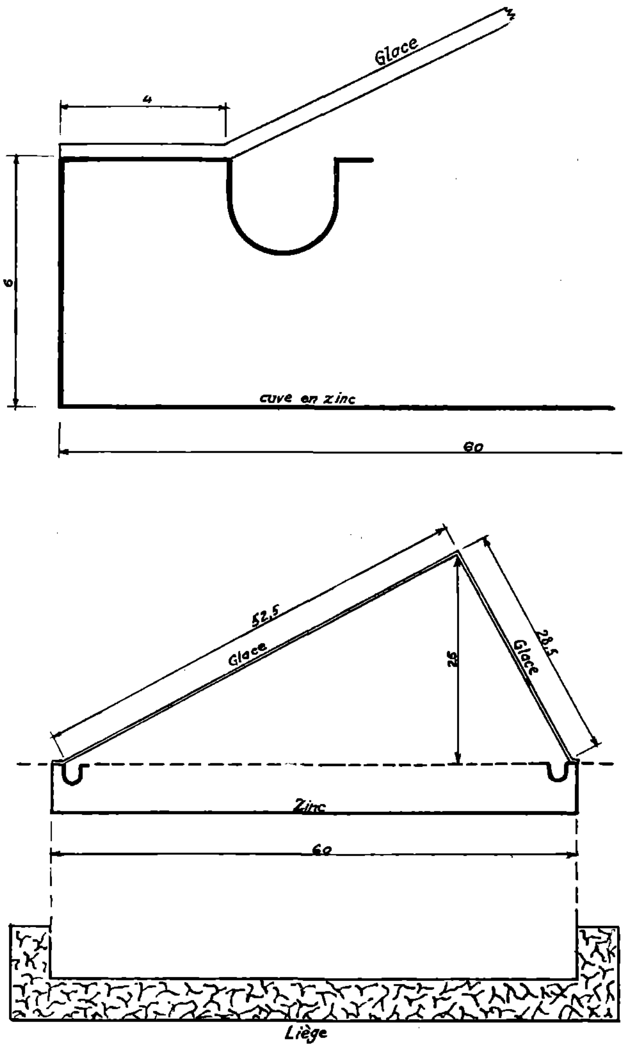

FIG. 1. Appareil de type I: schéma de construction.

Pratiquement, la phase de fonctionnement normal de l'appareil se situe entre le lever du soleil + 2 heures, et le coucher du soleil + 1 heure. Le maximum de rendement est atteint aux environs de 13–14 heures.

La persistance d'une faible distillation pendant les premières heures de la nuit est due à la différence de température entre le verre qui prend rapidement la température ambiante, et l'intérieur de la cuve dont la chute de température est moins rapide à cause de la forte capacité calorifique de l'eau et du revêtement isolant qui entoure la cuve.

Au cours des essais pour mesurer la variation du débit journalier sur un an, l'épaisseur d'eau a été maintenue aux environs de 4 à 5 mm. Les volumes journaliers maximum et minimum enregistrés au cours de chaque mois d'une année grégorienne — année 1954 — et ramenés à une surface de un mètre carré figurent au tableau 2.

TABLEAU 2. Variation du débit journalier sur un an

Mois	Volume		Température maximum	
	Minimum	Maximum	Moyenne	La plus forte
	l/m²/jour	l/m²/jour	°C	°C
Janvier	0,5	1,7	16,8	23,3
Février	0,6	1,8	18,9	28,5
Mars	0,6	2,2	23,2	29,5
Avril	1,2	3,2	22,9	30,0
Mai	1,6	4,1	32,3	36,7
Juin	2,3	4,3	36,4	41,3
Juillet	2,9	4,3	39,8	43,9
Août	3,0	4,4	39,9	43,1
Septembre	2,9	4,3	36,9	39,0
Octobre	2,4	3,4	28,8	34,1
Novembre	1,6	2,2	19,6	23,0
Décembre	0,4	1,6	20,6	24,2

A titre d'indication, le tableau 3 comporte quelques extraits des volumes journaliers recueillis (ramenés à une surface de un mètre carré) après la première période de mise au point effectuée à Rabat (année 1953).

TABLEAU 3.

Date	Volume	Température extérieure maximum
	litres	°C
20 mai	3,075	22
21 mai	3,225	22
22 mai	3,180	26
23 mai	4,060	29
15 juin	3,040	21
16 juin	3,360	24
17 juin	3,850	26
18 juin	4,330	26
19 juin	3,240	21

Il est évident que le débit maximum est le seul critère valable du rendement et de la qualité de l'appareil. En tout état de cause, on peut admettre que le débit de cet appareil se situe autour de 4 litres/m²/jour pour des températures comprises entre 30 et 40° et autour de 3 litres/m²/jour pour des températures comprises entre 21 et 25°.

Composition chimique de l'eau distillée. Une analyse sommaire de l'eau distillée a donné les résultats que l'on voit au tableau 4.

TABLEAU 4.

	Chlore (en Cl)	Alcalinité (en CO_3)	*p*H	*d*H	Résidu sec à 180°
	mg/l	mg/l			mg/l
Eau brute	382,5	228	6,9	62,5	1390
Eau distillée	4,5	5	7,7	2,5	25

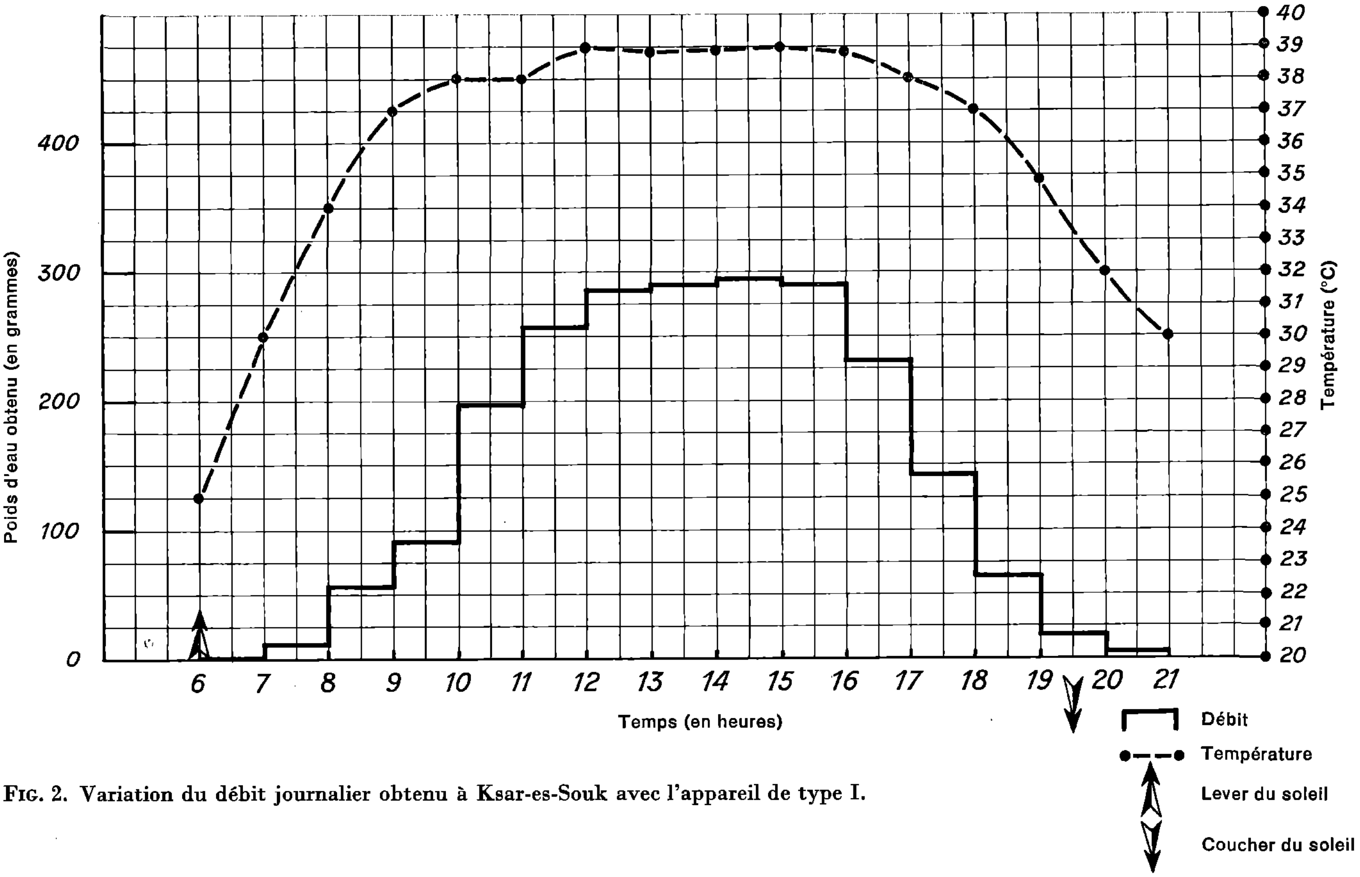

FIG. 2. Variation du débit journalier obtenu à Ksar-es-Souk avec l'appareil de type I.

Critique de l'appareil. 1° Quelques semaines d'utilisation révélèrent d'importantes fuites entre les vitres et leur châssis, de même qu'entre ce châssis et la cuve; parmi les différents produits d'étanchéité essayés, le plus efficace a été une dissolution de caoutchouc chargée de graphite. Mais les joints ainsi réalisés rendent l'appareil difficilement démontable. 2° D'autre part, l'eau condensée sur les parties métalliques plus chaudes du châssis se revaporise en partie, créant une perte de rendement certaine. 3° Le feutre intérieur qui cloisonnait la cuve était un frein au rendement, qui se maintenait autour de 2,4 litres/m^2/jour, pour une température extérieure de 21°. Sitôt le feutre enlevé, le débit est passé à 3 litres/m^2/jour pour la même température.

Variantes du type I. Pour pallier les difficultés rencontrées au cours de l'expérimentation de l'appareil type I, trois spécimens d'appareils constituant des variantes ont été construits:

Variante 1 (fig. 3): Construit par la Régie des exploitations industrielles (REI) en 1953, l'appareil comportait un châssis exclusivement en bois et verre; les gouttières étaient recouvertes de zinc, la hauteur du faîtage était de 70 cm, la surface insolée de 1 m^2 et le prix de revient de 35 000 FM par mètre carré. Les fuites restèrent nombreuses et une forte déformation du châssis en bois sous l'action de l'eau fit abandonner cet appareil après de courts essais.

Variante 2 (fig. 4): De construction très voisine de la variante 1; mêmes dimensions; seule innovation, le toit repose directement sur les gouttières et une bande

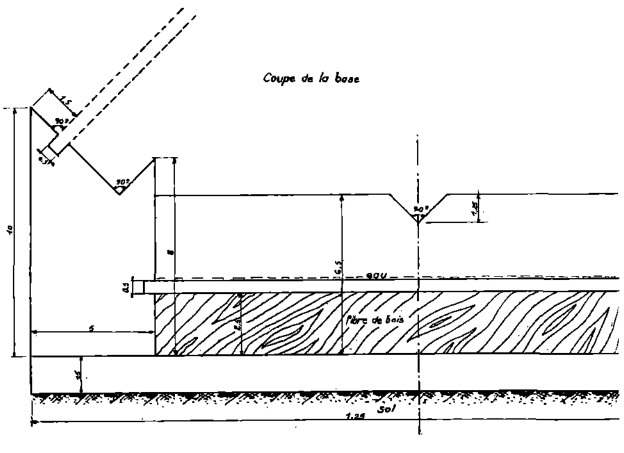

FIG. 3. Appareil de type I, variante 1: schéma de construction.

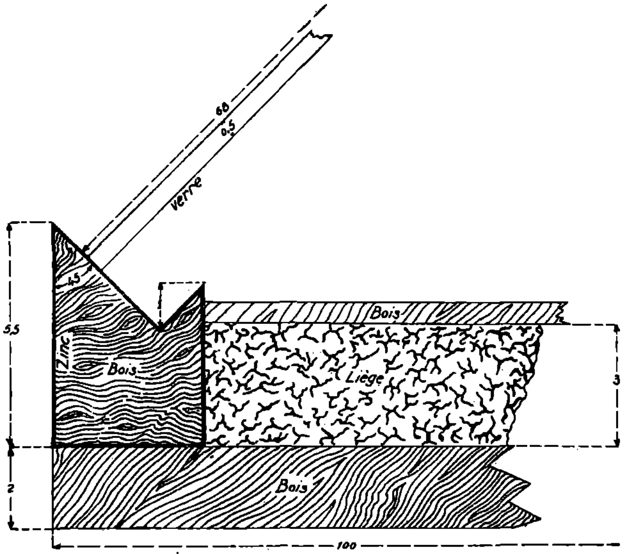

FIG. 4. Appareil de type I, variante 2: schéma de construction.

de caoutchouc assure l'étanchéité; le problème du joint verre-gouttière, source de fuites, est ainsi résolu. Le prix de revient est de 34 000 FM par mètre carré. Le rendement maximum enregistré au cours de l'été 1954 (août) a été de 4,5 litres/m²/jour pour des températures maximums de 43°.

Variante 3 (fig. 5). Construit par la REI, il se rapproche de la construction précédente: le toit est constitué par un châssis métallique maintenant des panneaux de plexiglas et repose directement sur les gouttières. L'étanchéité est assurée par une bande de mastic spécial, chargé de goudron, conservant sa plasticité au-delà des températures d'expérience. La hauteur du faîtage est de 47 cm et la surface insolée: 0,65 m². Cet appareil n'a jamais été mis en service.

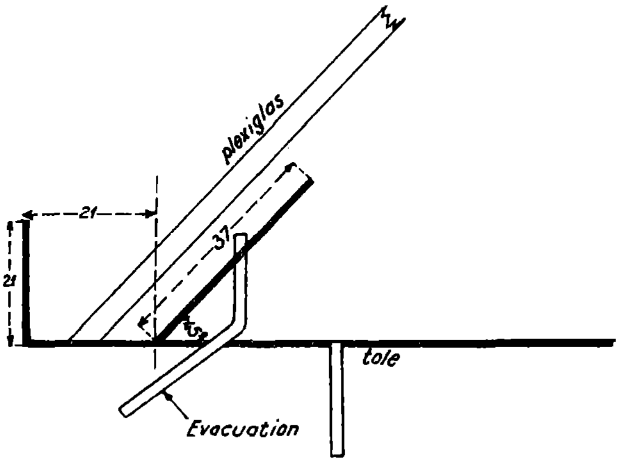

FIG. 5. Appareil de type I, variante 3: schéma de construction.

Type II[1]

A la différence du type I, cet appareil a été fabriqué entièrement en matière plastique.

Constructeur: Société Somaplas Maroc; année de fabrication: 1954; mise en service: avril 1954; prix de revient: 61 000 FM par mètre carré.

Rendement. Les mesures de la variation du débit en vingt-quatre heures sont enregistrées par un appareil automatique; dans le tableau 5, elles sont exprimées en poids d'eau distillée obtenu (ramené à une surface de un mètre carré); elles sont traduites également sur graphique (fig. 7).

TABLEAU 5. Variation du débit en vingt-quatre heures (septembre 1954)

	Heure	Température	Débit
		°C	g/m²
Lever du soleil	6 h	25	
	7 h	30	6
	8 h	34	57
	9 h	37	84
	10 h	38	138
	11 h	38	243
	12 h	39	305
	13 h	39	327
	14 h	39	327
	15 h	39	327
	16 h	39	317
	17 h	38	243
	18 h	37	177
Coucher du soleil	19 h	35	93
	20 h	32	28
	21 h	30	7

Cet appareil commence à condenser une heure avant celui du type I; en outre, la condensation de nuit, bien que négligeable, est supérieure dans l'appareil en matière plastique.

Le tableau 6 indique les volumes journaliers obtenus durant la saison chaude d'avril à septembre 1954 à Ksar-es-Souk, et ramenés à une surface de un mètre carré.

TABLEAU 6. Variation du débit journalier sur plusieurs mois

Mois	Volume		Température maximum	
	Minimum	Maximum	Moyenne	La plus forte
	l/m²/jour	l/m²/jour	°C	°C
Avril	1,8	3,4	22,9	30,0
Mai	2,2	3,6	32,3	36,7
Juin	2,6	3,8	36,4	41,3
Juillet	3,2	4,2	39,8	43,9
Août	3,4	4,5	39,9	43,1
Septembre	3,2	4,0	36,9	39,0

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[1] Voir fig. 6.

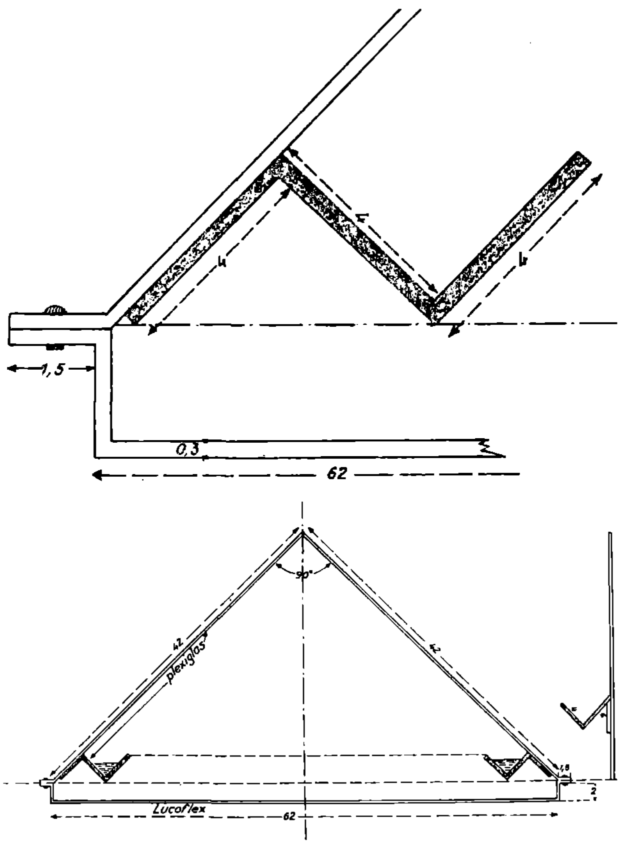

FIG. 6. Appareil de type II: schéma de construction.

Critique de l'appareil. 1° A la mise en service de cet appareil, le rendement était inférieur à celui du type I, qui servait de témoin de débit dans les mêmes conditions de température et d'exposition. Cette différence provenait du fait suivant: bien que l'appareil du type II commençât à condenser une heure avant celui de type I, le phénomène se ralentissait rapidement, car les gouttes d'eau se condensaient finement sur la paroi en plexiglas et ne pouvaient glisser ou glissaient mal vers les gouttières de réception; en somme, elles restaient collées et ne mouillaient pas la paroi. Cette condensation de fines gouttelettes sans écoulement formait un écran au rayonnement solaire. Pour pallier ce défaut, il convenait de modifier la valeur de la tension superficielle en recouvrant les faces de condensation d'une couche de silicones; après cette opération, le rendement a augmenté de 20 %. 2° Les gouttières étaient trop grandes et surtout placées trop haut, puisqu'une hauteur de 5 cm séparait leur base de la limite inférieure de la surface de condensation, ce qui représente une surface de 970 cm² où l'eau condensée revient à la cuve, soit une perte théorique de 10 % environ. 3° Dans les essais avec l'appareil du type I, on avait constaté qu'une condensation non négligeable avait lieu sur les parois latérales; l'appareil du type II a donc été muni de gouttières latérales, ce qui permet de récupérer un volume appréciable. En effet, au cours d'un essai de vingt-quatre heures, on a enregistré: sur la face nord, 240 cm³; sur la face sud, 220 cm³; sur les faces latérales (deux) 100 cm³. Cependant, il convient de préciser que les gouttières latérales s'appuient sur les faces nord et sud et recueillent, de ce fait, une partie de l'eau condensée sur ces faces de 3 520 cm² chacune. La fraction de surface intéressant les gouttières latérales est de 950 cm²; la quantité d'eau interceptée par ces gouttières latérales a donc été de 70 cm³. La condensation réelle sur les faces latérales représente en fait 30 cm³. Si les gouttières latérales étaient placées au plus bas, les surfaces latérales de condensation passeraient de 350 à 700 cm² et le débit de 30 à 60 cm³, soit 10 % du débit total de l'appareil; ce qui est loin d'être négligeable. 4° Les gouttières et les faces latérales se décollèrent après quatre mois d'utilisation; le collage a été remplacé par la soudure autogène des pièces à joindre au moyen de plexiglas appliqué sous forme monomère et polymérisé *in situ.* 5° La cuve en lucoflex se déforme par absorption d'eau et pourrait être remplacée avantageusement par du plexiglas, qui ne présente pas ce défaut et se fabrique en noir sans augmentation de prix.

Conclusions générales sur les types I et II

Rendement. Le rendement *théorique calculé* des appareils installés à Ksar-es-Souk, à 1 061 m d'altitude, par 31° 56′ de latitude N. et 4° 26′ de longitude O. s'établirait entre un maximum de 8,5 litres/m²/jour (21 juin), et un minimum de 2,9 litres/m²/jour (21 décembre).

Or, le rendement *pratique observé* des appareils expérimentés est compris entre un maximum de 3,6 à 4,5 litres/m²/jour (été), soit 42 à 55 % du rendement théorique maximum et un minimum de 1,6 litre/m²/jour (hiver), soit 55 % environ du rendement théorique minimum. Cependant, pour juger de l'efficacité d'un appareil, seul le débit maximum doit être pris en considération.

On peut en conclure que la conception des appareils expérimentés au Maroc, de quelque type qu'ils soient, ne permet pas de dépasser un rendement pratique supérieur à 50 % du rendement théorique.

Prix de revient. Il convient d'inclure dans le prix de revient: la construction, l'entretien, la revision générale (33 % de la construction au bout de cinq ans), les produits désincrustants, le prix de l'eau brute et l'amortissement (dix ans). Cela aboutit aux prix indiqués dans le tableau 7 (p. 376), établis sur dix ans, en francs marocains, pour un mètre carré de surface insolée.

Le rendement pratique annuel des appareils est le suivant:

Type I: 1,2 m³/m²/an (pour dix ans = 12 m³).
Type II: 1,1 m³/m²/an (pour dix ans = 11 m³).

Le prix de revient au m³ s'établit donc à:

Type I: 52 000/12 = 4 300 FM/m³.
Type II: 86 600/11 = 7 870 FM/m³.

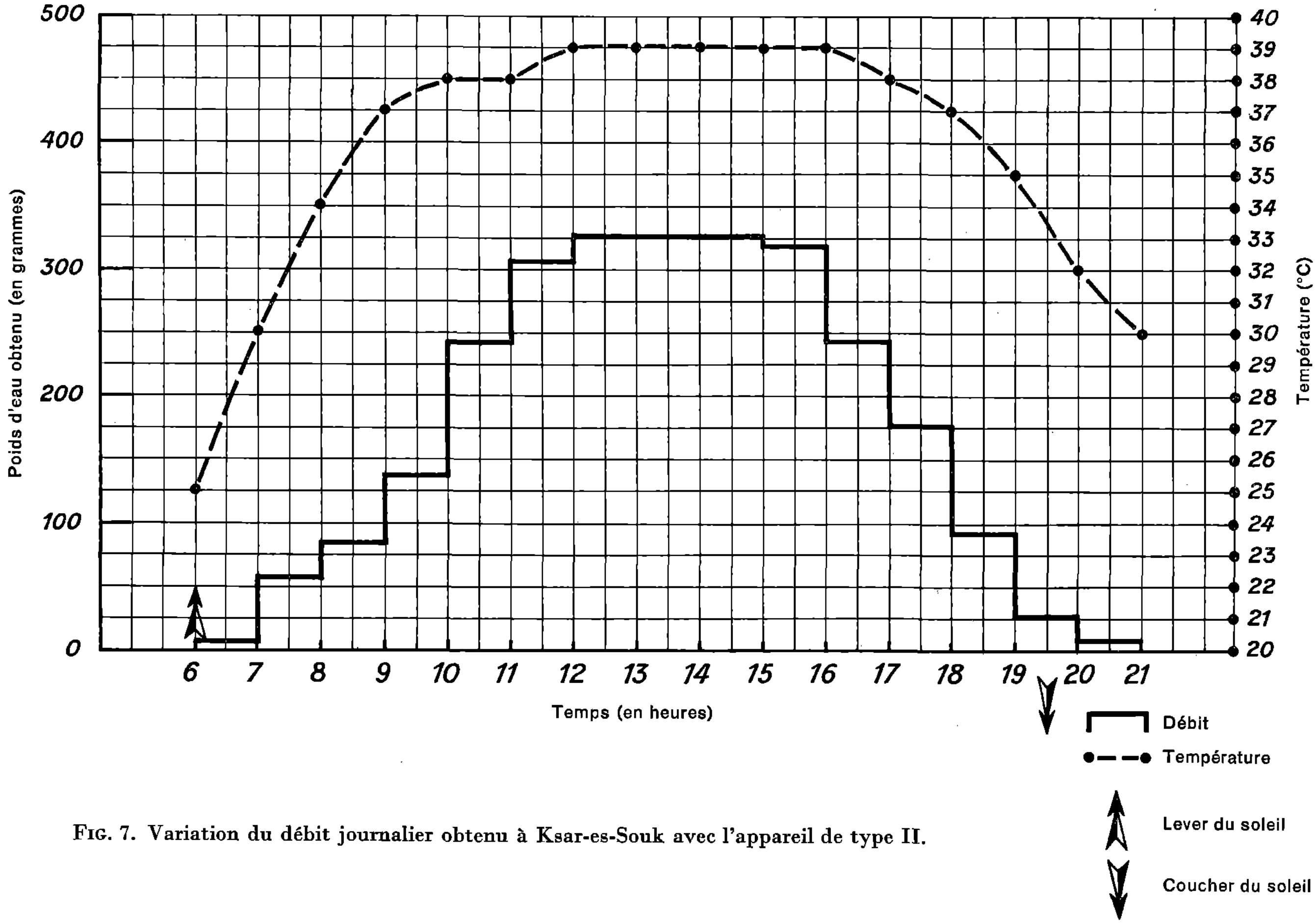

FIG. 7. Variation du débit journalier obtenu à Ksar-es-Souk avec l'appareil de type II.

TABLEAU 7.

Détail des dépenses	Type I	Type II
	FM	FM
Construction	35 000	61 000
Entretien	4 000	4 000
Revision générale (à cinq ans)	11 700	20 300
Produits désincrustants	1 000	1 000
Eau brute d'alimentation	300	300
Dépense totale	52 000	86 600

Principales difficultés à résoudre. a) Étanchéité totale et durable tout en maintenant la facilité d'entretien à l'intérieur de l'appareil; *b*) solidité et longévité des matériaux de construction soumis à des conditions climatiques exceptionnelles (chaleur, gros écarts de température entre le jour et la nuit, vents de sable, etc.); *c*) augmentation du rendement pratique; *d*) choix entre plexiglas et verre; il semble qu'il doive se faire en faveur du verre dont les seuls défauts sont le poids et la fragilité, alors que le plexiglas, bien que léger et incassable, présente plusieurs inconvénients: il se raye facilement et jaunit, d'où perte de la transparence totale; il est difficile à travailler, d'où entretien plus délicat des appareils; enfin, son prix est trop élevé.

EXPLOITATION CONTROLÉE DES APPAREILS "SÉTUDE" (ALGÉRIE)

Après la conférence d'Alger de mai 1955, les expériences sur les types d'appareils de fabrication locale furent arrêtées et remplacées par l'exploitation contrôlée, en divers centres, d'un appareil de fabrication algérienne: l'appareil Sétude type amiante-ciment 10 × 10 (voir fig. 8). L'idée retenue était de doter tous les services régionaux du Centre des études hydrogéologiques du Maroc (à l'exception de Casablanca): Oujda, Fès, Meknès, Ksar-es-Souk, Rabat, Marrakech et Agadir. Cela représentait une bonne répartition géographique.

Sept appareils du type précité de 1,25 m^2 de surface insolée furent livrés depuis Alger aux divers points envisagés, par chemin de fer et camion, soit un transport minimum de 600 km et maximum de 2 000 km. Trois appareils seulement arrivèrent en bon état: ceux destinés à Oujda, Fès et Meknès, c'est-à-dire ceux qui avaient

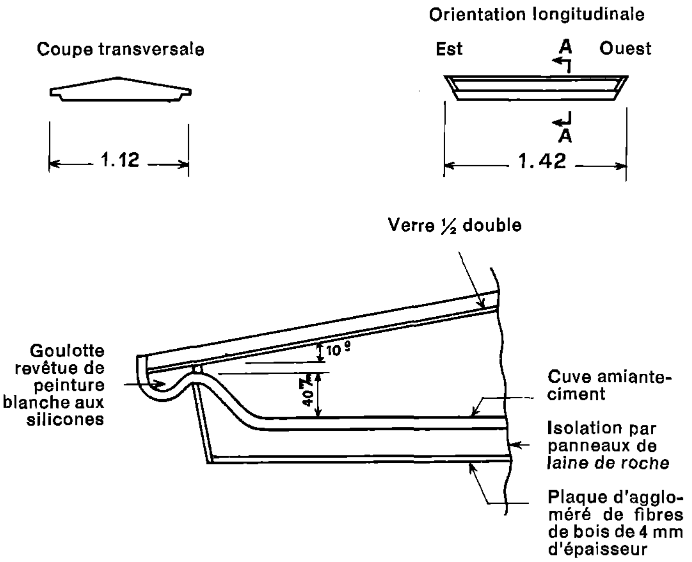

FIG. 8. Appareil à distillation par énergie solaire. Type amiante-ciment 10 × 10 (Algérie).

parcouru le trajet le plus court et uniquement par voie ferrée. Les autres ne purent être mis en service. Enfin, l'appareil de Fès fut brisé accidentellement après son montage. Il restait donc deux stations équipées: Oujda et Meknès. Avant d'examiner les résultats obtenus sur ces stations, il convient de rappeler brièvement la conception et la construction de l'appareil utilisé.

Constructeur: Société d'études pour le traitement et l'utilisation des eaux (Sétude) sous la direction de M. Gomella, pour le compte du Service de la colonisation et de l'hydraulique d'Algérie; année de construction 1954–1955; prix de revient: 18850 FM par mètre carré, rendu Maroc.

Résultats obtenus à Oujda. Oujda est située a 34° 45′ de latitude N., 1° 55′ de longitude O., et à 459 m d'altitude.

L'observation de la variation du débit au cours d'une journée a été faite le 14 août 1958 (lever du soleil 5 h 27, coucher du soleil: 18 h 56), sur une période de douze heures au cours de laquelle le volume total d'eau distillée recueilli à été de 3,54 litres/m². Le rendement en eau distillée a été mesuré toutes les heures en poids et ramené à une surface de un mètre carré; les mesures sont consignées dans le tableau 8 et traduites sur graphique (fig. 9).

Le démarrage du phénomène après le lever du soleil est très lent en raison semble-t-il des brouillards matinaux. Sur l'ensemble de l'expérience, on peut conclure que la période de fonctionnement efficace de l'appareil, en été, n'excède pas neuf heures sur vingt-quatre.

L'appareil d'Oujda est en fonctionnement continu depuis deux ans; il a été mis en service en juin 1956 et les dernières observations consignées sont de juillet 1958. En ne considérant que le maximum et le minimum de débit journalier au mètre carré enregistrés au cours de chaque mois, on aboutit au tableau 9.

Les plus grands écarts de rendement apparaissent durant la saison chaude, de mai à septembre, et notamment au cours de l'été 1957. Le maximum de débit obtenu: 7,2 litres/m²/jour, s'établit à 85 % du rendement théorique maximum.

TABLEAU 8. Variation du débit au cours d'une journée

Heure	Température	Débit
	°C	g/m²
7 h	21	
8 h	25	6
9 h	26	18
10 h	27	44
11 h	28	250
12 h	31	378
13 h	34	555
14 h	34	562
15 h	34	588
16 h	34	422
17 h	34	368
18 h	34	224
19 h	33	125

TABLEAU 9. Variation du débit journalier sur deux ans

Mois	Volume		Température	
	Minimum	Maximum	Moyenne des minimums du mois	Moyenne des maximums du mois
	l/m²/jour	l/m²/jour	°C	°C
Août 1956	2,8	5,6	18	33,6
Septembre	—	—	15,4	29,6
Octobre	0,4	3,7	11,8	25,6
Novembre	0,4	2,2	5,1	17,5
Décembre	0,4	1,1	2,5	15,4
Janvier 1957	0,2	1,6	1,6	14
Février	1,4	2,8	4,9	20,6
Mars	1,2	3,4	8,7	21
Avril	1,6	4,2	8,5	18,6
Mai	—	—	10,6	23,2
Juin	2,2	7,2	12,7	26,6
Juillet	3,2	5,5	17,2	32,6
Août	3,4	5,4	18,5	33,9
Septembre	2,6	6,2	16,3	31,8
Octobre	1,2	3,1	11,5	23,6
Novembre	0,6	2,0	7,8	17,4
Décembre	0,3	1,5	3,8	13,8
Janvier 1958	0,5	1,2	5,3	14,4
Février	0,6	2,2	8	19,1
Mars	1,2	3,0	6,1	19
Avril	1,8	3,3	7,2	19,1
Mai	2,6	4,3	12,4	27,5
Juin	3,4	4,6	14,7	29,2
Juillet	3,8	4,7	16,5	32,1

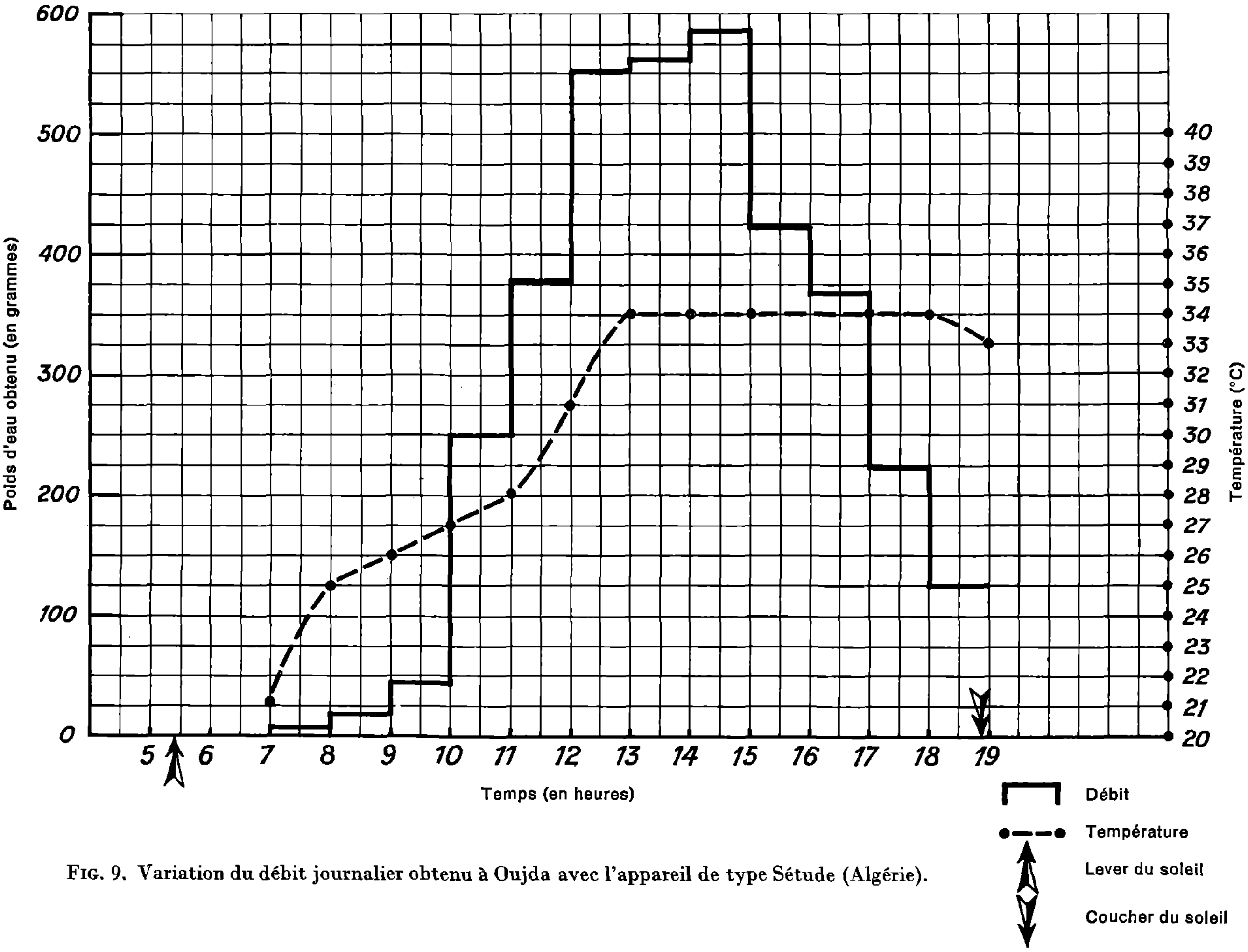

FIG. 9. Variation du débit journalier obtenu à Oujda avec l'appareil de type Sétude (Algérie).

En conclusion, le rendement pratique obtenu avec cet appareil est en général supérieur à celui qui est obtenu avec les appareils des types I et II, à Ksar-es-Souk, où cependant les conditions climatiques étaient plus favorables.

D'autre part, si l'on porte sur un graphique (fig. 10) les moyennes mensuelles des débits journaliers en regard de la moyenne mensuelle des températures maximums et minimums journalières, on constate une baisse de rendement de l'appareil; cette baisse paraît constante en été comme en hiver alors que les températures sont homologues d'une année à l'autre.

La cause est à rechercher sans doute dans la perte de transparence du verre, l'encroûtement de l'appareil, etc., si bien qu'une revision annuelle (et non quinquennale) sérieuse paraît indispensable.

Résultats obtenus à Meknès. Meknès est situé à 33° 53′ de latitude N., 5° 33′ de longitude W., et à 532 m d'altitude.

L'observation de la variation du débit au cours d'une journée a été faite le 2 octobre 1956 (lever du soleil: 6 h 18, coucher 18 h 6), sur une période de douze heures au cours de laquelle le volume total d'eau distillée recueillie a été de 2,66 litres/m². Le rendement en eau distillée a été mesuré toutes les heures, en poids et ramené à une surface de un mètre carré.

Les mesures sont consignées dans le tableau 10 et traduites sur graphique (fig. 11).

Comme à Oujda, on constate que le démarrage du phénomène, après le lever du soleil, est très lent (environ quatre heures); est-ce dû ici encore aux brouillards matinaux, ou n'est-ce pas plutôt dû à l'abaissement très fort durant la nuit de la température de l'eau de la cuve (inférieure à 20°)? En effet, on constate que pour obtenir un rendement correct il faut que la température de l'eau de cuve ait dépassé 40°. En fait, à cette époque de l'année, la période de fonctionnement efficace n'excède pas six heures sur vingt-quatre.

Après une période d'essais, l'appareil de Meknès a été

TABLEAU 10. Variation du débit au cours d'une journée

Heures	Température de l'eau	Température de l'air	Débit
	°C	°C	g/m²
9 h	20	21,5	
10 h	33	22	3
11 h	47	24,5	80
12 h	56	27	345
13 h	60	28,5	395
14 h	60	29	518
15 h	50	30	446
16 h	42	29,5	374
17 h	35	28,5	256
18 h	35	25	136
19 h	28	23,5	52
20 h	25	20,5	35
21 h	23	20	17

mis en fonctionnement continu du 3 octobre 1956 au 1^er^ mai 1957. En ne considérant que le maximum et le minimum du débit journalier au mètre carré enregistrés au cours de chaque mois, on aboutit au tableau 11.

Il est à remarquer que les minimums de 0,34, 0,58 et 0,61 ont été obtenus par jours de pluie et par temps froid. Dans certains cas, malgré des journées pluvieuses, le débit de l'appareil oscillait entre 0,9 et 1,36 litre/m²/jour.

Le maximum de débit obtenu, 6,5 litres/m²/jour, s'établit à 77 % du rendement théorique maximum. Encore convient-il de préciser que ce débit a été obtenu en avril, alors que le rendement théorique maximum est calculé pour le mois de juin. Une comparaison des stations de Meknès et d'Oujda à la même période d'avril fait ressortir un net avantage du rendement en faveur de l'appareil de Meknès. Il est regrettable que les observations à Meknès n'aient pas pu être poussées au-delà d'avril 1957.

TABLEAU 11. Variation du débit journalier sur plusieurs mois

Mois	Volume		Température	
	Minimum	Maximum	Moyenne des minimums du mois	Moyenne des maximums du mois
	l/m²/jour	l/m²/jour	°C	°C
Octobre 1956	0,90	3,20	14,1	27,1
Novembre	0,34	2,90	6,6	16,9
Décembre	0,74	4,35	3,4	15,2
Janvier 1957	0,61	1,86	3,4	13,6
Février	1,71	3,10	6,4	19,4
Mars	0,58	4,38	9,2	21,5
Avril	0,72	6,5	8,4	18,4

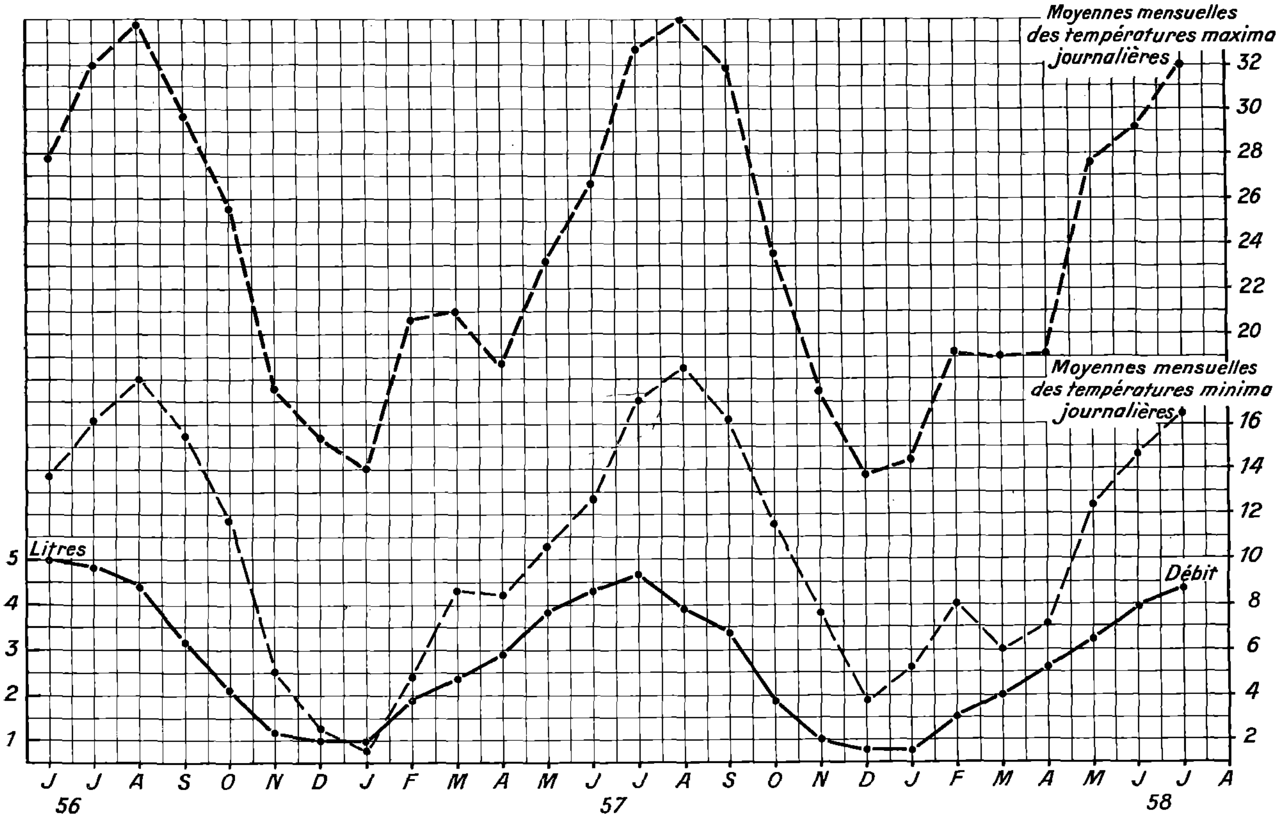

FIG. 10. Courbe des moyennes mensuelles des rendements journaliers à Oujda.

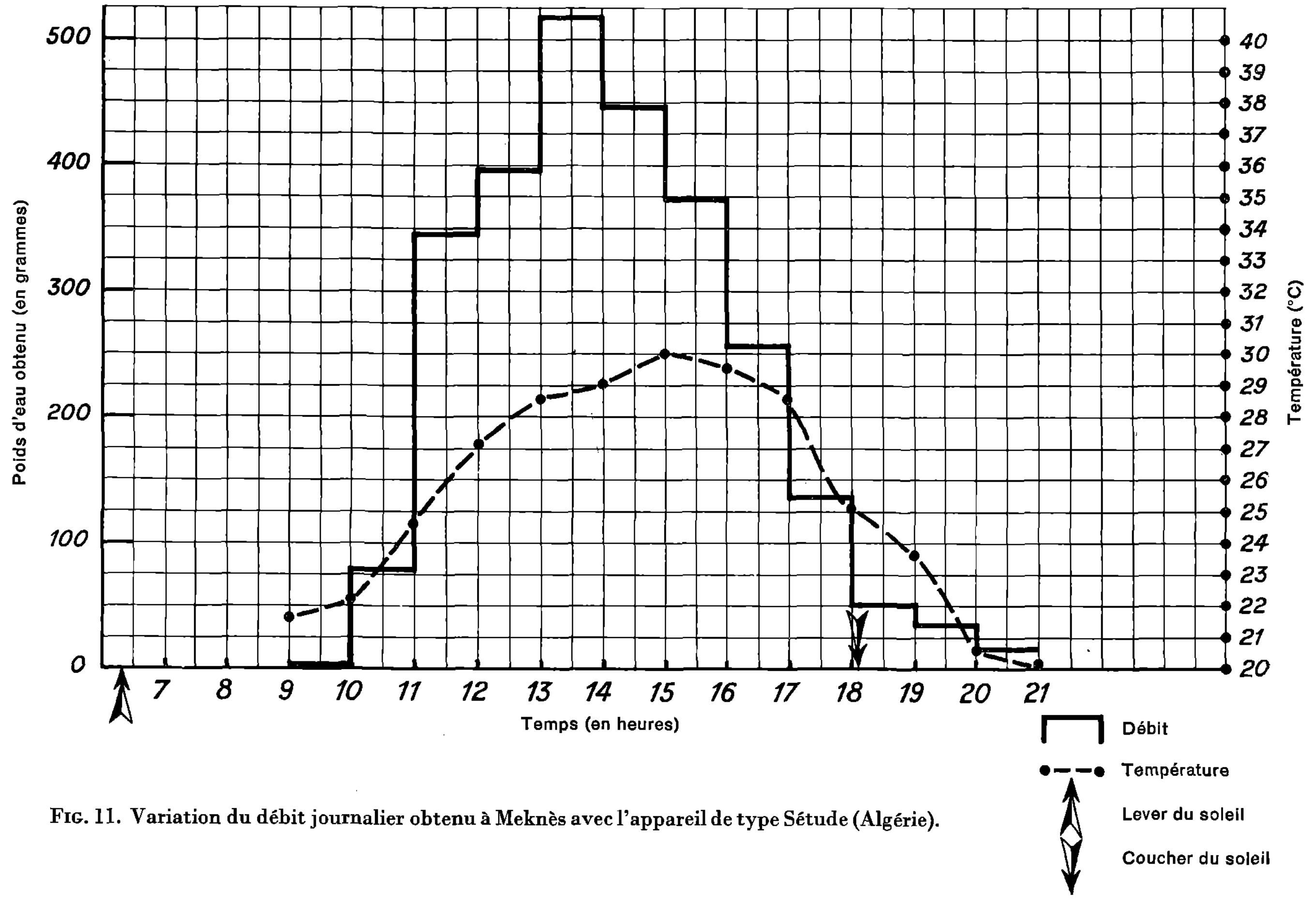

FIG. 11. Variation du débit journalier obtenu à Meknès avec l'appareil de type Sétude (Algérie).

CONCLUSIONS

En prenant comme référence le rendement maximum, seul critère valable, il ressort que les appareils "Sétude" (Algérie) 10 × 10 en amiante-ciment et verre ont un rendement pratique supérieur à celui des appareils réalisés au Maroc. En effet, leur rendement pratique maximum étudié à Oujda et Meknès — dans les moins bonnes conditions climatiques du Maroc — s'établit entre 77 et 85 % du rendement théorique maximum, alors que les appareils de type I et II réalisés au Maroc avaient un rendement pratique maximum compris entre 42 et 55 % du rendement théorique maximum.

Cependant, une critique doit être formulée à l'encontre des appareils "Sétude" en amiante-ciment: leur fragilité dans le transport. L'expérience de livraison au Maroc depuis Alger par voie ferrée et par camion a démontré que quatre appareils sur sept sont parvenus à destination hors d'état de fonctionner. Il reste à renforcer la solidité de la cuve.

BILAN DES RECHERCHES ET PERSPECTIVES

De tous les procédés de déminéralisation, la distillation solaire est sans conteste le moins onéreux. Mais, dans l'état actuel des recherches, il est exclu d'envisager le dessalement des eaux d'irrigation, des eaux industrielles ou des eaux d'alimentation de grands centres, qui exigeraient des installations sur une grande échelle. En revanche, la fabrication d'eau de boisson par ce procédé peut recevoir une solution dans le cas de petits centres, d'installations domestiques de fermes, de postes isolés, de chantiers, etc., au moyen des appareils unitaires de distillation solaire; dans de bonnes conditions de fonctionnement, chaque appareil unitaire peut assurer la boisson de deux personnes, compte tenu de ce que l'eau distillée est additionnée d'une fraction d'eau saumâtre pour la rendre potable.

D'après les recherches effectuées au Maroc, l'appareil qui est actuellement le mieux adapté est l'appareil amiante-ciment 10 × 10 type "Sétude". Cet appareil se rapproche le plus des conditions recherchées: prix de revient modeste, bon rendement, entretien peu onéreux et emploi facile. Il aurait pu être concurrencé par celui en matière plastique du type II, si ce n'était le prix de revient de ce matériau. Donc, l'appareil 10 × 10 amiante-ciment et verre représente la meilleure réalisation du moment pour les petits problèmes de l'Afrique du Nord.

Cependant l'emploi de cet appareil, même utilisé à de nombreux exemplaires, ne saurait aller au-delà de ces modestes besoins, même si l'on groupe un certain nombre d'appareils. Dans le cas d'alimentation en eau d'une petite ville ou d'un centre, il faut recourir à un système plus important, qui utiliserait toujours l'énergie solaire dont dispose abondamment le Maroc aride. En particulier, il se présente au Maroc deux cas extrêmement importants, qui réclament une solution urgente, surtout le premier:

Tarfaya (ex-Cap Juby), à 600 km au sud d'Agadir, dispose d'une eau à 3890 mg/litre de résidu sec; les besoins en eau potable seraient de 3 à 10 m^3/jour, soit une production journalière de 2 à 7 m^3 d'eau distillée;

Erfoud (Tafilalt) dispose d'une eau à 3945 mg/litre de résidu sec; les besoins en eau potable seraient de 25 à 30 m^3/jour, soit une production journalière de 17 à 20 m^3 d'eau distillée.

Ces problèmes exigent que le Maroc entre dans une phase de recherches semi-industrielles de la distillation solaire et crée une grande station expérimentale couvrant plusieurs centaines de mètres carrés de surface ensoleillée en s'inspirant des études poursuivies aux États-Unis d'Amérique, particulièrement en Californie, à San Diego, et dans le Massachusetts. On envisagerait également un système mixte combinant l'appareil à distillation solaire avec un four solaire qui réchaufferait l'eau à l'admission.

TABLEAU 12. Critères comparés des appareils "Maroc" et "Algérie"

Caractéristiques	Maroc		Algérie
	Type I	Type II	Type "Sétude" 10 × 10
Matériaux et construction			
Toit			
Châssis	Bois et métal	Néant	Faîtière en tube
Panneaux	Verre	Plexiglas	Verre
Hauteur du faîtage	0,25 m	0,30 m	0,13 m
Inclinaison des panneaux	28° et 62°	45°	10°
Cuve			
Matériau	Zinc	Lucoflex	Amiante-ciment
Surface insolée	0,54 m^2	0,54 m^2	1,25 m^2
Isolation	Liège	Liège	Laine de roche
Étanchéité	Caoutchouc et colle de caoutchouc graphitée	Caoutchouc	Boudins de mastic
Rendement			
Période de fonctionnement efficace sur 24 h	8 h	8 h	6 à 9 h
Débit journalier max. Été	4,3 l/m^2	4,5 l/m^2	7,2 l/m^2
Hiver	1,6 l/m^2	?	1,5 l/m^2
Débit moyen annuel	3,12 l/m^2/jour	?	3,74 l/m^2/jour
$R = \frac{\text{Rendement pratique maximum}}{\text{Rendement théorique maximum}}$	42 %	55 %	85 %
$r = \frac{\text{Rendement pratique minimum}}{\text{Rendement théorique minimum}}$	55 %	55 %	52 %
Prix de revient			
Appareil (à la construction)	35 000 FM	61 000 FM	15 000 FM
m^3 d'eau distillée	4 300 FM	7 870 FM	900 à 1 300 FM
Construction			
Nom	SMD	Somaplas	Sétude
Année de fabrication	1953	1954	1954
Période et lieu d'expérimentation			
Année de mise en service	1953	1954	1956
Période	1953–1954	1954 (avril–septembre)	1956–1958
Lieu	Ksar-es-Souk	Ksar-es-Souk	Oujda, Meknès

SUMMARY

Research carried out in Morocco on the demineralization of saline and brackish waters by solar distillation
(R. Ambroggi)

The author reports that 50 per cent of the underground water in Morocco is of medium or poor quality and frequently non-potable, but that 70 per cent of this water has to be used for the needs of the population.

Solar distillation is without doubt the least troublesome of all demineralization processes, but at the present time it is not possible to envisage the use of this process for the desalting of water for irrigation or industrial purposes or of drinking water for large urban centres, all of which necessitate large-scale installations. On the other hand, small solar distillation units can be successfully used for the production of drinking water for small centres, domestic installations for farms, isolated posts, working sites, etc.; when functioning well, each unit can provide drinking water for two persons, it being understood that a small amount of brackish water is added to the distilled water to render it potable.

From the work carried out in Morocco, it seems that the asbestos-cement 10 × 10 type "Sétude" apparatus is the one that conforms most closely to the conditions required: modest selling price, good output, simplicity of use and maintenance. The Type II in plastic would be competitive if it were not for the selling price of the material.

However, for the provision of water for a small town or centre a more elaborate system must be employed, which means that Morocco must enter into a phase of semi-industrial research into solar distillation and set up a large experimental station covering a sunny area of some several hundreds of square metres. A system should also be considered that would combine a solar still with a solar furnace.

DISCUSSION

G. Drouhin. (1) M. Ambroggi peut-il nous donner une idée plus précise de la combinaison de fours solaires et d'appareils du type "serre"?

(2) Quel serait le type de four solaire employé?

R. Ambroggi. (1) Le four solaire serait orienté vers la pipe d'admission du distillateur solaire du type ordinaire, afin que l'eau entrant dans le distillateur soit réchauffée à 60° C. Cette température serait maintenue constante par un réglage du débit par venturi.

(2) Le four solaire employé serait un four parabolique de un mètre de diamètre, tel un parapluie recouvert intérieurement de feuilles d'aluminium.

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AN EXPERIMENT WITH A VERTICAL SOLAR STILL

by
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In the present paper a solar still of a new design is described.[1] It is characterized by a vertical structure; in general, solar stills consist of assembled horizontal trays containing the salt water and covered by a tight inclined glass roof.

During the Saline Water Symposium held in Washington, D.C., in November 1957 [12][2], Dr. Wilson of the Commonwealth Scientific and Industrial Research Organization of Melbourne, Australia, described a solar still in which four trays were assembled one upon the other in a room surrounded by glass plates.

Such stills have been designed in order to collect the solar radiation when the inclination of the sun is low, as is the case in the arctic regions.

The author of this paper has extended this design and has built the solar still illustrated in Plates XXI and XXII. There are four rectangular trays, each 1 × 3 × 0.13 ft. (3 sq.ft.) assembled in a glass cage closed at the bottom by an inclined iron plate. The trays are made of aluminium, electrolytically blackened.

The distance between the trays is about 10 inches. The trays are surrounded by hot still air and this ensures good insulation for the water heated by the solar radiation and minimizes the heat losses through the bottom of the trays; such losses may be great in horizontal solar stills.

The orientation of the still is east-west, with the inclined face oriented to the south.

The water to be distilled is introduced in the first upper tray through an inlet tube and then passes into the lower trays. The heat of the sun is absorbed by the water in the black trays; the water evaporates and the water vapour condenses on the inner surfaces of the glass cage; it is collected at the bottom and then in the measuring vessel.

The preliminary results for the first two months of experimenting are contained in fig. 1, representing the daily water production in relation to the daily sun radiation on an horizontal surface.

From this graph it appears that about 550 BTU/sq.ft./day are necessary to warm the still in order that distillation should begin.

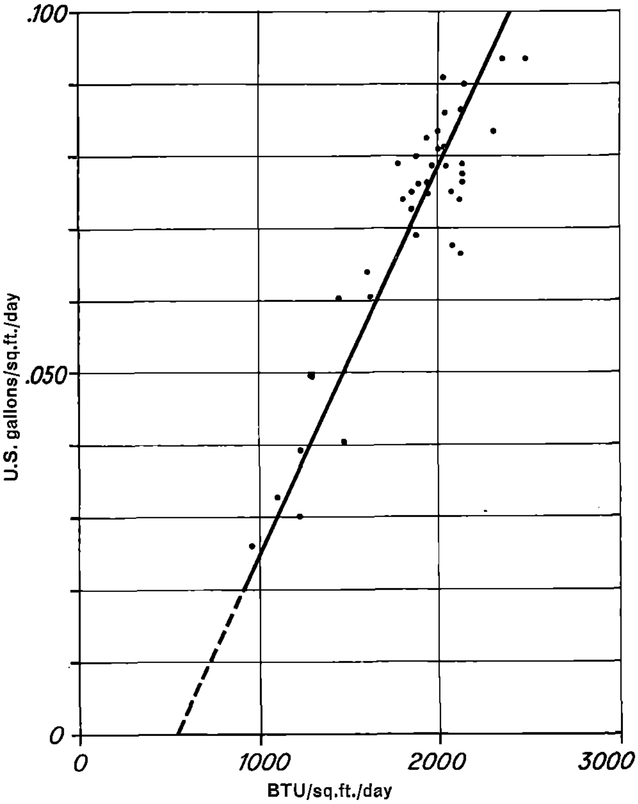

FIG. 1. Daily water production in relation to daily sun radiation on an horizontal surface (2-month period).

When the distillation has begun, a further 1,850 BTU (approx.) of solar energy are required to distill 0.100 U.S. gallons of water. This represents a utilization of 50 per cent of the incident radiation, considering that

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[1] This is the experimental solar still, model No. 7. For other experiments see publications referred to under 4, 5, 6, 7, 8, 9, 10 in the bibliography on page 385.

[2] The figures in brackets refer to the bibliography on page 385.

in a simple distillation process, operating at atmospheric pressure, about 9,200 BTU are required per gallon of distilled water.

All these considerations refer to the whole surface of the trays, i.e. 12 sq.ft.

However, the tray surface reached by the solar radiation varies greatly at the different hours of the day; it is about 12 sq.ft. until the inclination of the sun is lower than 35°; when this inclination increases the upper tray is always exposed but the lower ones are decreasingly exposed, being shaded by the others.

The amount of distilled water per unit of covered ground is very large.

Its evident efficiency and the simplicity with which it is assembled suggest that the vertical still is a promising device for distilling saline water.

RÉSUMÉ

Compte rendu d'une expérience portant sur l'emploi d'un distillateur solaire "vertical" (G. Nebbia)

On a expérimenté un distillateur solaire dont les plateaux sont placés dans la position verticale — et non horizontale comme ils le sont d'habitude — en vue de réduire les pertes de chaleur qui se produisent à travers le fond et de diminuer la superficie occupée par l'appareil.

L'eau salée est contenue dans quatre plateaux de 0,27 m^2 chacun et placés dans un espace clos de plaques de verre.

Les plaques de verre et les plateaux sont montés sur un châssis de fer; les plateaux sont en aluminium noirci.

L'auteur indique quelles quantités d'eau ont été obtenues et il commente les résultats de cette expérience.

DISCUSSION

C. **Gomella**. Quelle a été la méthode de calcul utilisée par le professeur Nebbia pour déterminer l'énergie rayonnante réellement reçue par l'appareil?

Avant d'écouter la réponse du professeur, je voudrais ajouter que le très intéressant appareil décrit est particulièrement adapté aux pays de latitude élevée, alors que, près de l'équateur, seul le plateau supérieur recevrait une quantité notable d'énergie.

G. **Nebbia**. (1) The solar energy intensities are available to me through the courtesy of the Italian Air Force, which has established a network of heliometric stations in Italy. The data of the Bologna station are elaborated at the Meteorological Office of the Air Force and then are made available to me.

(2) The figure of 50 per cent for the proportion of solar energy used has been calculated as follows:

About 1,500 Kcal./mg./day are necessary to heat the still. When the distillation has begun it is possible to observe the following data (average) which refers to the total surface of all four trays:

l./mg./day[1]	Kcal./mg./day[1]
2	4 000
2.5	4 600
3	5 200
3.5	5 800

Since about 600 Kcal. are necessary to evaporate 1 litre of water at 70°C., and since an increment of 600 Kcal. in solar radiation caused an increase in water production of about ½ litre, I have stated that the percentage of incident solar energy used for distillation is about 50.

(3) I agree completely with Dr. Gomella's observation that the utility of the still would be greater in temperate zones.

G. **Drouhin**. M. le professeur Nebbia a-t-il fait quelques mesures pour déterminer les rendements respectifs des plateaux successifs?

G. **Nebbia**. No. I have available only the maximum temperatures of the trays, from top to bottom, from 12.00 to 14.00 hours. They are about 65–70, 55–60, 45–50 and 35–40° C. respectively, with external air temperatures of about 30–35° C.

R. **Ambroggi**. Le professeur Nebbia peut-il préciser:

(1) Depuis quelle date cet appareil est en fonctionnement? Depuis quel mois?

(2) Quels sont les meilleurs rendements obtenus?

G. **Nebbia**. (1) The solar still data have been collected since June 1958. For June and July solar energy intensities are now available and correlation is possible. The still is still working (October 1958); complete correlation between water production and solar energy intensity will be available in the future.

(2) The best results are:

Date	Water production per 1.08 sq.m.[1]	l./sq.m./day	Solar energy intensity Kcal./sq.m./day
29. 6. 58	4.15	3.8	6 700
3. 7. 58	4.15	3.8	6 370

[1] Surface of all four trays.

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THE COSTS OF DEMINERALIZING WATER

by

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It is often stated that the main problem in the study of demineralizing processes is an economic one. While this statement is admittedly valid, it is equally true that the costs of producing water are most difficult of estimation and that estimated costs for similar processes appearing in the literature are often in serious disagreement. There seems to be some confusion in the various publications on the demineralizing of water between the value, the price, and the cost of water. Since the present paper is concerned only with the cost, it is well to present definitions of the three quantities and thus outline the scope to be considered.

Value is defined as the intrinsic worth of water to the consumer. The value of water has a variety of magnitudes which are nearly as great as the variety of uses to which it may be put. Since water is essential to plant and animal life, it may have an almost infinite value to the individual whose life is at stake in the desert or on a raft at sea. Water also has a high value to the householder or subsistence farmer who is located in a semi-arid region.

The price paid for water generally has little relation to its value as defined above. Price is based partly on supply and demand but may depend heavily on items such as the fraction of costs which are declared to be non-reimbursible. It is dependent on the scheme used for financing the project in so far as the costs due to capital expenditures are concerned.

The cost of water may be defined as the sum of the charges assignable to the entire production process. Normally the components of cost are divided into three general categories; namely, the costs due to capital investment, those due to fuel or power requirements, and those due to maintenance and operation items. The relative magnitudes as well as the importance of the respective categories depends on the nature of the use as well as upon the process or type of development involved.

Before dealing with detailed considerations of costs, it is well to point out the difficulty of assigning costs by an example. One may cite the case of the water from the Colorado river, which is imported into Southern California by the Metropolitan Water District. A summary of water delivered and money expended during the period 1941–56 was recently presented by Milliman [17].[1] During this first 15-year period of the aqueduct's use, only a portion of its full capacity was needed and used. At the same time, the retirement of capital invested went on at full rate. The result was that the quotient obtained by dividing the total money expended by the total water delivered would amount to a little over $65 per acre-foot. Milliman further computed this quotient for metropolitan Los Angeles, where most of the taxes were collected but where very little of the water was used and concluded that, in effect, the water had cost $1,200 per acre-foot in this limited area. These figures are widely different from the prices paid for the water, which averaged a little less than $14 per acre-foot and probably represented the costs of operating and maintaining the system. Had there been immediate need for full capacity operation of the system, the quotients cited by Milliman would have been much lower. However, with the past history of the project and the probable date of full utilization some time later than 1975, it is impossible to estimate the true average cost of water to be obtained from this project during its useful life, say the first 50 years. While this probably represents an extreme situation, it does illustrate the difficulty of obtaining the true costs of water, whether it is produced by a conventional system or by a demineralizing plant.

Turning now to the three categories of cost outlined above—capital costs; fuel and power costs; maintenance and operating costs—it is proposed to consider each category separately before discussing the possibilities of various processes.

CAPITAL EXPENDITURES

Capital expenditures may be compared on the basis of the total magnitude, on the basis of the magnitude per

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[1] The figures in brackets refer to the bibliography on page 394.

TABLE 1. Demineralizing processes: classification on basis of degree of refinement of energy

Processes using			
Direct energy	Mechanical energy	Electrical energy	Chemical energy
Multi-effect distillation Supercritical distillation Vacuum flash distillation Solar distillation	Vapour compression distillation Freezing Reversed osmosis	Electrolysis Electrodialysis	Ion exchange Precipitation

unit daily capacity, or on the charge to be assessed per unit volume of water. The total magnitude is important for small plants which furnish water to ultimate consumers, rather than to production processes. Examples of these applications would be to families for potable supplies or for subsistence farming. The magnitude per unit of daily capacity would be important for applications where different debt-retirement programmes are being considered. The magnitude per unit volume of water is of importance to agricultural and industrial users in cases where the amortization of capital is included in the price assessed for water and must therefore be included in the costs of the articles produced. In this paper primary emphasis will be given to the magnitude per unit of daily capacity, since this number is independent of the type of financing decided upon and can be easily related to either the total cost or to the cost per unit volume of water produced. To provide a preliminary landmark for magnitudes, it may be observed that the design conditions of normal water supply developments in the U.S.A. result in costs of about $0.50 per daily gallon of capacity for the simplest river diversion and filtration scheme, and in costs as high as $4 per gallon of daily capacity for reservoir and aqueduct systems of large magnitude. It could be inferred that, to be competitive in the U.S.A., water demineralizing plants should cost no more than these figures and probably should cost somewhat less, since the useful life of demineralizing units is likely to be much shorter than the 50 to 100 years for which reservoirs and aqueducts are supposed to be serviceable. Methods for evaluating the costs of equipment and its installation are given in various publications and are well summarized in the "Standardized Procedure" of the Office of Saline Water (OSW) [26].

FUEL AND POWER COSTS

Fuel and power costs are of interest not only for their effect on the over-all cost but also because the value in energy units is an index of the efficiency of the separatory process being used. The basis for computing efficiencies is the comparison with the energy demand of an ideal completely reversible process. This latter quantity may be computed from basic thermodynamic considerations and has been evaluated by many writers. For details of these calculations the writings of Murphy [19], Tribus [25] and Gilliland [7] should be consulted. The theoretical work of separation may be expressed in many units and in the U.S.A. is generally given in kWh per 1,000 U.S. gallons, the number for normal sea water being about 2.8 in these units. For saline waters of concentrations less than that of sea water, the energy required for separation is correspondingly less and of course is zero for zero salinity.

As Gilliland [7] has pointed out there must be a head loss in any practical piece of equipment and the corresponding energy loss will be proportional to the flow rate through the device. By considering a head loss of 50 ft. to be supplied with a motor-driven pump of 70 per cent over-all efficiency he concludes that the total energy requirement for the sum of practical pumping and ideal separation energies will be a minimum of 4.4 kWh per 1,000 gallons when about 28 per cent of the sea water feed is recovered as fresh water output. For water containing only 1 per cent of salt the corresponding minimum energy is 2 kWh per 1,000 gallons and occurs at about 40 per cent recovery of fresh water from the saline input.

Since the above figures are very general they may be used for comparing the performance of systems using different methods of fresh water recovery.

The several methods for demineralizing water may be classified on many different bases. Two classifications are significant for this paper, the first relating to the degree of refinement of the energy to be utilized and the second to the variation of the energy required with the initial salinity of the water. These two classifications are given in Tables 1 and 2.

TABLE 2. Demineralizing processes: classification on basis of variation of energy requirement with initial salinity

Processes in which energy requirement	
Is independent of initial salinity	Depends on initial salinity
Multi-effect distillation Vapour compression distillation Supercritical distillation Vacuum flash distillation Freezing Reversed osmosis (considered as a mechanical sieving operation)	Electrodialysis Ion exchange Chemical precipitation

Table 1 presumes that the primary form of energy is that of heat, and that this energy may be transformed successively into mechanical energy and into electrical energy. Each of these transformations is accompanied by losses so that 1 BTU of electrical energy represents about 1.2 BTU of mechanical energy or nearly 4 BTU of heat energy. Chemical energy, when represented by manufactured materials, is available in usable form only after processing in which energy originating as heat has been utilized. From this table it may be concluded that in considering comparative energy or fuel costs it will be desirable to refer to the same base, say heat energy. This would eliminate the lack of correspondence between fuel costs and electrical costs so often found in estimates.

Table 2 lists the same processes as appear in Table 1 but has them divided into two groups. The first group includes all of the processes for which the energy requirement is essentially independent of the initial salinity of the water supply, and the second group includes the processes for which the energy requirement is strongly influenced by the initial salinity. Reversed osmosis is included in the first group since its general development at this time is one in which the product water is forced through the osmotic membrane. If a process were found by which the ions were forced through the membrane, then such a process would fall in the second group. For the purification of waters of low salinity, processes in the second group would seem preferable from the energy point of view.

Since the different processes use energy in different forms as indicated in Table 1, it is desirable to find some common measure of the effectiveness of separation. For the purposes of this paper the common measure chosen is the ratio of the weight of fresh water produced to the weight of oil fuel expended in producing the water. This ratio is proportional to the efficiency of separation. Fig. 1 shows the relation of this ratio to the more common quantities of kWh of power per 1,000 gallons and pounds of water per pound of steam. Assumptions basic to this figure are as follows: (a) the fuel is a liquid hydrocarbon with heating value of 18,500 BTU per lb.; (b) the conversion of heat energy to electrical energy is accomplished with an over-all efficiency of 25 per cent; (c) steam is produced with a combustion or fuel efficiency of 85 per cent; (d) the latent heat of vaporization is taken as 1,000 BTU per lb. for the process steam.

It should be noted that the maximum ordinate on the figure, $1{,}000\ \frac{\text{lb. water}}{\text{lb. fuel}}$, represents an approach factor to the ideal minimum for sea water conversion of approximately four. This seems to the writer to be a reasonable goal with which to compare advances as they occur.

The magnitudes achieved to date are indicated on fig. 1. Solid lines correspond to the figures achieved in actual plants and dotted lines show the estimates made for various schemes as indicated.

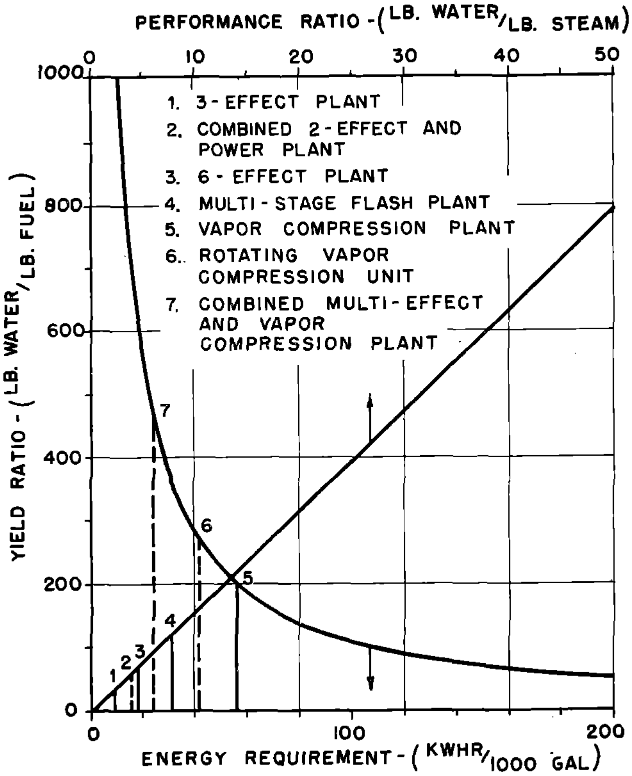

FIG. 1. Fuel economy comparison.

Maintenance and operating costs

Costs in this category are probably the most difficult to obtain. The most accurate scheme is to plan the detailed layout of the plant and its schedule of operation. From this one can visualize the type and quantities of labour, overheads and materials needed. The OSW scheme previously mentioned [26] gives a basis for preliminary estimates and relates some of the items to the total plant investment. The scheme includes consideration of raw materials such as chemicals, general supplies and maintenance materials, operating labour and maintenance labour. Because of the great difference in the demands of various processes, the costs of maintenance and operation cannot be readily generalized. In the following sections, which apply to individual processes, an attempt will be made to point out the relative importance of this item.

MULTI-EFFECT DISTILLATION

This is the only scheme which has been used in very large plants up to the present time. The oldest and most advanced development of this scheme has been in the field of marine applications, where high costs of fresh water production are permissible if the cargo space thereby saved will earn more than the cost of the water production process. The saving in cargo space is evaluated with due consideration given to the additional fuel space required as well as to the difference between space occupied by the distiller equipment and the alternative water tankage requirements. A good summary of experience in marine applications was presented by Ireland [12]. He gave a number of representative examples and showed that for one specific case a large high speed passenger vessel could produce 105,000 gpd. of distillate at a cost in excess of $2.50 per 1,000 gallons and still show an annual profit of over $45,000 due to the release of space for other purposes. From this and other similar examples it will be appreciated that the development of marine plants gave major emphasis to compactness and dependability rather than to fuel economy. The first large land-based distiller plants followed marine practice rather closely, but recently designs for land-based plants have departed widely from the space restrictions previously followed.

The question of ultimate minimum costs for water produced by multi-effect land-based plants has been discussed recently by Gilliland [7], Sonderman [24], Silver [22], Badger [2], Williamson and Stewart [27], and Elliott [6]. Multi-effect processes had been regarded as much too expensive for consideration in the U.S.A. until 1955, when Gilliland [7] published an analytical expression for the cost of water as a function of the number of effects and other variables. His mathematical analysis showed that with reasonable values for the several constants, costs of the order of $0.33 per 1,000 gallons for steam and equipment charges might be attainable with from 10 to 17 effects. Badger [2] estimated costs and performance of a plant to produce 17 mgd. with 12 effects and arrived at a total cost of about $0.30 per 1,000 gallons. His estimates were predicated on the prevention of scale deposition at very low cost and the use of all-steel construction (i.e., assuming corrosion prevention at no cost). He is at present testing the latter two premises under the auspices of the U.S. Department of the Interior. Sonderman [24] has come to the conclusion that $1 per 1,000 gallons is a reasonable minimum to be expected, using shell and tube construction, and bases his conclusion on the experience of his firm in building the 2.7 mdg. 6-effect plant at Aruba. The Aruba plant cost about $4 per gpd. of capacity and produces salable power as well as water. The water is estimated to cost $1.75 per 1,000 gallons, of which fuel costs are $0.80, maintenance and operation $0.30, and capital charges $0.65. By making use of recent advances in equipment design and the expanded sale of by-product power, Sonderman feels the above costs can be both substantially reduced and partially offset by power sales so that his estimate of $1 per 1,000 gallons may be realized. The conclusion that electric power sales could be so effective in reducing costs must be tempered by the relation between power and water consumptions in the U.S.A. pointed out by the author [10]. This relation is such that in an urban community about 15 to 20 gpd. *per capita*, about one-seventh of the average water consumption, could be produced if *all* of the electric power generating capacity were used as a source of waste heat for the operation of distillers.

Since the fuel cost quoted above is a major fraction of the total cost, it is well to consider magnitudes and trends in this quantity. The magnitude of the yield ratio, i.e., the ratio of distillate to steam required, varies directly with the number of effects and is 2.3 for 3-effect and 4.6 for 6-effect submerged-coil plants. For multistage flash plants the relation is not direct, as indicated by Silver [22], but may be of the order of 6 to 8 when many flash stages are used. The 12-effect plant proposed by Badger [2] would have a yield ratio of slightly less than 12, and the unconventional rotating 30-effect unit proposed by Bromley [4] would possibly have a yield ratio of nearly 30. The water to fuel ratio for the marine plant cited by Ireland [12] would amount to about 64 for a 2-effect plant since the distiller plant uses steam which has been partially expended in the turbines and is therefore primarily chargeable to power generation rather than to the distiller plant. From the several current developments, it would seem that fuel costs will be reduced both through improved efficiency brought about by an increase in the number of effects used and by a concurrent generation of salable electric power in which the distiller steam supply passes first through the power turbines.

Maintenance and operating costs other than fuel have been evaluated by Ireland [12] at $1 per 1,000 gallons and by Sonderman [24] at $0.30 per 1,000 gallons. It seems unlikely that much lower figures can be attained with equipment as complex as that involved in multi-effect distillation.

Capital expenditures are reliably reported to lie in the range $2–$5 per daily gallon of capacity, with the average lying close to $4 per gpd. Some reduction may be accomplished by all-steel construction of the heat exchangers, since these items represent a large fraction of the cost and at present are generally installed with bronze or copper-nickel tubes and tube sheets.

If one attempts to summarize progress in this field for the past 10 years, the following points should be noted:

1. The maximum capacity of a single train of heat exchangers has been increased from 120,000 gpd. in 1952 to over 500,000 gpd. in 1957.
2. Techniques for control of scale have been developed so that the "down-time" for scale removal from heat transfer surfaces is now very small.
3. There is a current trend toward increasing the number of effects and hence the efficiency.
4. Appreciable economies of operational costs are being urged through the sale of by-product power.

VAPOUR COMPRESSION DISTILLATION

Like multi-effect distillation, vapour compression was first developed for use on board ships. Its wide acceptance is quite recent, having occurred during World War II on naval vessels. Since then it has been applied to a number of land-based installations where its low fuel rate was particularly attractive. Studies of economy and potential development have been made by Latham [15], Campobasso [5], and Leitner [16]. These studies have involved the use of a submerged-coil type evaporator-condenser similar to those used in multi-effect plants, together with a direct-displacement type blower. The latter unit is preferred rather than the axial-flow or centrifugal blowers because its use makes possible full capacity operation even when the heat exchanger surface has become covered with scale formed from the chemicals in the sea water. Latham [15] and Campobasso [5] studied the relative costs of power, of maintenance and operation, and of equipment as affected by the difference in temperature across the heat transfer surface, and concluded that minimum over-all costs would result when the differential temperature was maintained at 10°F. Also, studies were made of the effect on costs of the size of unit, with the conclusion that the total cost could be as low as about $1.40 per 1,000 gallons if units as large as 120,000 gpd. could be built. Revisions of this figure to bring power and fuel costs into line with those of other writers would reduce it to about $1.25 per 1,000 gallons. However, the largest units built to date have been rated at 50,000 gpd., for which size Latham's figures [15] modified for power costs would total about $1.35 per 1,000 gallons.

The vapour compression system requires auxiliary heat for starting as well as for offsetting the heat losses from the piping and heat exchangers. Isolated units are hence often driven by diesel engines with the waste heat from these engines used for the make-up heat noted above. This type of drive has turned out to be quite economical and water to fuel ratios of 200 have been recorded in production units. Under clean conditions ratios as high as 300 have been achieved. Experiments on forced circulation [3] give promise of even better performance through the achievement of increased over-all heat transfer factors.

The cost of equipment for this system, using steam turbine drive but not including the steam boiler, has been estimated by Leitner [16] as slightly less than $0.85 per gpd. Estimates on a 2 mgd. unit for use with saline water have been made by Smith and Richheimer [23], and show a cost of $1.50 per gpd. Leitner [16] compared the cost of 6-effect distillers with vapour compression equipment and concluded that in a plant producing approximately 380,000 gpd. the steam-turbine-driven vapour compression units would cost nearly 30 per cent more than 6-effect distiller units. From these meagre data it may be concluded that the cost of vapour compression equipment without steam generating equipment or diesel engine drive is slightly more than the cost of multi-effect units of equal capacity. This would mean that capital costs of the order of $1.50–$2.00 per gpd. could be expected.

Fuel rates for the vapour compression system have been reported in the range of 50–70 kWh per 1,000 gallons, corresponding to the water-to-fuel ratios of 200 to 300 previously noted. Since these ratios are the highest for any commercial equipment it is clear that the vapour compression process at present has the highest efficiency of separation. So far as fuel cost is concerned, the maximum efficiency quoted has been achieved with diesel engine drive and the more highly refined fuel needed by this equipment is more expensive than the oil fuel needed for producing steam in the multi-effect plants. This higher unit fuel cost may partially cancel out the fuel economy advantage in specific cases.

Cost of maintenance and operation have been estimated by Latham [15] for the 50,000-gpd. size to be about $0.24 per 1,000 gallons. Smith and Richheimer [23] give estimates of $0.37 for this item. These data are inconclusive, but serve to establish the order of magnitude for maintenance and operation at about $0.30 per 1,000 gallons.

Before leaving the subject of the vapour compression process, the work of Hickman [9] should be mentioned. The rotating heat transfer surface developed by him is an attempt to increase fuel economy through the use of lower temperature differentials for heat transfer and, in turn, smaller compression ratios for the steam compressor. Economies possible with this scheme will involve full consideration of vacuum pumping equipment and rotor drive as well as of the compressor unit itself. Data available now do not permit refined cost predictions at this time, although Hickman predicts an energy demand of about 40 kWh per 1,000 gallons for a 25,000-gpd. unit.

COMBINED PLANTS

Proposals to increase fuel economy through combining vapour compression and multi-effect plants have been made by several writers, but no prototype plants are in operation at this time. The most recent proposals are those of Badger [2] and Larrecq [14]. Badger's proposal, based on his many years as a consultant on evaporators for the salt industry, involves the use of conventional steam generating units supplying steam to back pressure steam turbines. Part of the turbines drive steam compressors in a vapour compression section of the plant, while the balance drive electric generators for supplying power to pumps, etc. All the turbines discharge steam to the multi-effect distiller section of the plant. Thus, the two sections of the plant, vapour compression and multi-effect, are in parallel and are relatively independent. Badger's estimated cost for a 1.25-mgd. plant is approximately $0.91 per gpd.

Larrecq's proposal uses a free-piston gas generator to supply gas to a gas turbine which drives a steam compressor. This steam compressor receives steam from the final evaporator of an 8-effect distiller plant and delivers the compressed steam to the first effect of that same plant. Thus the vapour compression and multi-effect plants are in series in this case. The use of the gas turbine and generator would be an innovation in so far as distillation plants are concerned. Larrecq's estimates indicate a capital cost of $1.50 per gpd. for a plant to produce 2.5 mgd. and a water to fuel ratio of 460 for the entire plant.

Either one of the above combinations could be assembled from components now commercially available.

ELECTRODIALYSIS

Electrodialysis equipment is not yet fully developed in the sense that there are relatively few installations of large size and the period of operation of these installations is quite limited. The plant at Bahrain has the longest history, having been installed in 1955 and enlarged to 86,500 gpd. in 1957. A plant capable of handling 3,000,000 gpd. is being built in South Africa. Recently a contract for a plant to produce 28,000 gpd. has been awarded to the Ionics, Incorporated, by the city of Coalinga, California. When these and possible additional plants have been operated for a few years it will be feasible to predict costs and performance with some confidence. Preliminary figures by Katz [13] indicate capital costs for a 1-mgd. plant to be of the order $0.43 per gpd. for demineralizing water of about 1,000 ppm. initial salinity. For sea water the number of stacks in series would probably be five or more and the capital cost would be increased to something more than $1 per gpd. At present membrane replacement costs are high, representing about 50 per cent of the operating costs. It is reasonable to expect that membrane developments will lead to lowered first costs and increased life so that operating costs should tend to decrease as time goes on.

Electrodialysis has a great advantage over distillation in that the energy required is in proportion to the salts removed rather than to the water produced. For this reason it should meet the need of purification of saline (up to, say, 5,000 ppm.) water. If it can be operated at a high efficiency of separation it could make the demineralizing of such saline waters competitive with natural supplies. This probably could come about only in very large plants.

OTHER METHODS

To attempt to predict costs without at least pilot plant installations would be rather pointless. However, there are several promising methods in early stages of development which bear mentioning at this time. There are at present no large producing plants for solar distillation. The small asbestos cement units developed by Gomella in Algeria and adapted to Australian conditions by Wilson have reached a semi-commercial stage in those two countries. The largest single plant in the U.S.A. is probably the University of California experimental plant which has an aggregate collector surface of approximately 1,500 sq.ft. and has been in partial operation for over six years. Present indications are that solar distillation in sizes up to 100 gpd. should ultimately cost about $10 per gpd., can be produced on at least a partial "do-it-yourself" basis, and under these conditions may find a fair market for isolated homes in power-short areas. Reports on cost-reducing efforts in the U.S.A. will be found in the paper by Mr. David Jenkins on page 307.

"Cold distillation" or separation by freezing has been regarded by several recent authors as one of the most promising methods for low-cost separation. The low latent heat of fusion as compared with the latent heat of evaporation, together with the possible recycling of heat by a heat pump, led Gilliland [7] to conclude that power consumptions could be very attractive if a satisfactory method of separating ice and brine could be achieved. The most successful separatory scheme yet devised is the counter-current washing process reported by Ashley [1]. The cost of producing the ice by normal ice-machines has been demonstrated by Hendrickson [8] to be prohibitively expensive. Freeze-evaporation was proposed by Zarchin [21] in 1953 and shown by Ashley to be low in its energy demand. So far, costs of equipment are uncertain but several estimates of costs from $0.30 to $0.50 per 1,000 gallons have appeared.

Ion exchange is another promising method for demineralizing saline water, since the chemical requirement is proportional to the initial salinity rather than to the water produced. Modern exchange materials are increasingly efficient and should reduce costs below the $0.60 per 1,000 gallons for each 1,000 ppm. removed generally quoted. For sea water chemical regeneration is prohibitively expensive but the use of heat regeneration as suggested by Gilliland [7] may prove to be economical. The general scheme is to use exchanger materials which can be regenerated by the salts of volatile materials, as, for example, ammonium bicarbonate. Tests in progress at the University of California have disclosed some of the newer exchange materials which have the desired capacity. The problem of stripping the product water of the ammonia and CO_2 gases is now under study.

Another method which seems to have some promise is that of reversed osmosis. If regarded as a mechanical sieving process, this method has the advantage that no phase change is involved. Work so far has been chiefly concerned with either the search for appropriate membranes or the fabrication of ultra-filters. Work under Office of Saline Water auspices, and reported by Mr. David Jenkins in another paper, has surveyed numerous plastic materials and disclosed some with limited useful life-periods. Tests at the University of California have been concerned with both the search for suitable materials and the development of ultra-filters. So far, one material has been found which will screen out the salts from sea water, but the low throughput per unit area of membrane would require exorbitant capital costs. Tests of mechanically constructed ultra-filters have not yet shown successful screening of ions. If suitable membranes can be found or made it is probable that low energy demand will be found, but the cost of equipment is unpredictable at this time.

SOURCES OF ENERGY

If one accepts the low efficiency of separation of the multi-effect process, some economy may be possible through the concurrent generation of power and production of water as previously indicated. In these cases the economy effected may be expressed either in terms of a reduced fuel cost or in terms of an increased water to fuel ratio. Since the former computation involves a hypothetical and variable selling price for the by-product power the latter computation is preferred by the writer. For this computation, the fuel chargeable to the water production process is that needed to provide the difference in steam flow through the turbines when in one case steam is discharged at about atmospheric pressure to the water plant, and in the other case steam is expanded in the turbines to the lowest pressure consistent with current engineering practice. For example, the water to steam ratio is approximately doubled when back pressure steam is used at atmospheric pressure in a plant in which steam is generated at 1,000°F. and 1,000 psi. and would normally be expanded to an absolute pressure of 1.5 in./Hg. This gain is indicated in fig. 1.

Another possible fuel saving results from the use of low temperature waste heat or from solar heat which has been absorbed in the ocean. In these cases vacuum flash distillation is possible if the warm water source is at least 15°F. in temperature above the available cooling water. In the case of using solar heat from the ocean, the "available" cooling water is water from the depths of 1,500 ft. or more and must be pumped into the plant. The latent heat for evaporation is obtained by the cooling through a small temperature range of the entire supply of warm water. The limited range of temperature requires the circulation through the plant of warm water quantities from 100 to 200 times the amount of fresh water produced and hence requires appreciable energy. Estimates of Nizery [20] and Mulford [18] together with some test data at the University of California [11] indicate energy demands for pumping and vacuum of approximately 40 kWh per 1,000 gallons. It has been pointed out that this entire energy demand can be supplied by a turbine wheel interposed between the evaporator and condenser, provided the total initial difference in temperature of the warm and cold water supplies is as much as 30°F. There are some locations where coastal marine canyons and favourable vertical ocean temperature gradients exist in which large ocean plants could well be considered. There are also some instances where appreciable quantities of warm cooling water must be disposed of and where there is a simultaneous need for demineralized water. Estcourt of the Pacific Gas and Electric Company, in an unpublished communication to the writer, has suggested the consideration of the vacuum flash system for producing boiler make-up water from condenser cooling water in electric generating plants which operate at variable loads and have appreciable periods of off-peak operation at poor heat rates.

A discussion of energy sources would be quite incomplete without some mention of nuclear resources and development. At the present state of development nuclear plants are producing electric power with equivalent fuel costs somewhat in excess of those presently applicable to fossil fuel plants. However, the trends of both capital and operating costs indicate considerable reductions in costs to be possible in large plants, of the order of 850 megawatts (heat) or more. Since distillation plants of this size have not been built as yet it is well to consider the matter of size along with that of nuclear energy.

SIZE OF PLANT

The cost per unit of capacity of heat exchangers, pumps and related equipment decreases as size increases up to the maximum possible output of a single set of equipment. Beyond this limit some further economies may come about through manifolding of piping and similar joint services, but in general the increase in cost will be proportional to the increase in capacity. The question then arises as to the maximum possible outputs to be achieved in single sets of equipment corresponding to minimum capital expenditures. Turning first to existing plants and equipment it is observed that the multi-effect plants at Aruba and Kuwait can produce 500,000 to 600,000 gpd. per train of heat exchangers. The largest vapour compression plants will produce about 50,000 gpd. per compressor. The standard electrodialysis stack built by Ionics, Incorporated, is said to have a capacity of 20 gpm., equal to 288,000 gpd. if on a once-through continuous flow circuit. Whether or not capital costs of demineralizing plants can be decreased radically will depend on whether or not the above maximum sizes of single assemblies can be greatly increased. Wilson [28] has suggested that radically new concepts of equipment construction may be needed if distillation is to be carried out on the scale needed for water supplies. If one sets out to design a plant for 100 mgd. is there no alternative to the conventional surface heat exchanger? Is the concept of 200 trains of heat exchangers in parallel an acceptable one?

Nuclear plants for the generation of heat energy are also subject to the size effect so far as cost is concerned. Preliminary studies indicate that nuclear plants are much too expensive at rates of heat generation less than about 850 megawatts. Assuming a steam distilling plant with a possible water to steam ratio of 6 indicates that the 850-megawatt nuclear reactor should produce at least 50 mgd. of water. As indicated in the preceding paragraph, the design of a distiller plant to match an economical nuclear reactor will be a challenge to those working in the distillation field. A simple multiplicity of small plants will probably not be acceptable. Thus, the consideration of nuclear energy will force researchers and designers alike to consider the very large sizes of plant which are also needed in water supply but which may be neglected in the research programmes because of the many as yet unsolved problems associated with small plants.

RÉSUMÉ

Prix de revient de l'eau déminéralisée (Everett D. Howe)

Le coût de l'eau déminéralisée se distingue de sa valeur et de son prix de vente et se définit comme la somme de trois éléments, à savoir: la charge résultant des dépenses d'investissement, les dépenses de combustible et d'énergie et les frais d'entretien et de fonctionnement. Ces trois éléments sont donc considérés séparément en ce qui concerne le problème général et les méthodes particulières de déminéralisation de l'eau.

Les dépenses d'investissement sont traitées de façon variable et sont plus ou moins importantes selon l'usage auquel on les destine. L'auteur fait remarquer que, pour une installation de déminéralisation destinée à alimenter un petit groupe, la première condition pour que les dépenses afférentes aux investissements soient jugées acceptables est que l'usager soit en mesure de les supporter. Les incidences budgétaires d'un projet municipal de déminéralisation varient selon le programme de financement adopté, de sorte que, pour comparer les avantages respectifs des différentes méthodes, le plus raisonnable semble être de prendre comme base le coût de l'unité calculé d'après le rendement journalier. Le coût de l'unité de volume d'eau produite est d'un intérêt primordial pour les consommateurs qui se servent de l'eau pour produire d'autres articles. Ainsi, la méthode de base pour évaluer les dépenses afférentes aux investissements est le coût de l'unité calculé d'après le rendement journalier. Il convient de remarquer que les chiffres publiés pour la nouvelle installation de distillation d'Aruba donneraient un prix de revient d'environ 1 000 dollars des États-Unis par mètre cube et par jour.

Pour les procédés existants, les dépenses de combustible et d'énergie peuvent être déterminées avec suffisamment de précision, tandis que pour les procédés nouveaux, les estimations sont tout à fait sujettes à caution. Cependant, ce sont les procédés encore imparfaitement au point (électrodialyse, échanges d'ions, osmose inversée et congélation) qui semblent offrir le plus de possibilités de réduire considérablement les quantités d'énergie nécessaires.

Les frais d'entretien et de fonctionnement autres que ceux de combustible et d'énergie sont les plus difficiles à évaluer. L'auteur résume les rares études faites à ce sujet et indique les facteurs employés dans les procédés normaux d'estimation.

La conclusion générale à tirer de ces remarques est que plusieurs procédés devraient permettre d'atteindre en quelques années l'objectif de 100 dollars des États-Unis par *acre-foot* (ce qui représente un volume d'environ 1200 mètres cubes). Une réduction substantielle de ce prix ne pourra être obtenue qu'après quelques années d'exploitation d'installations à prix de revient faible.

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