Experiments in the Improvement of Saline and Alkaline Soils of the Zebra Plain (Morocco)

by

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Situated in eastern Morocco, in contact with the Rif and the Middle Atlas range on the left bank of the Moulouya, 35 km from the Mediterranean, the Oued Zebra plain forms part of the great watershed of the Lower Moulouya which will embody nearly 80,000 ha of lands under irrigation; the Zebra plain itself will be irrigated over an area of some 10,000 ha.

The Zebra plain is a vast synclinal which throughout the quaternary was filled in by alluvions and colluvions, usually sandy-argillaceous and nearly always strongly calcareous. Protected against marine influences by the small Riffian chain of the Kebdana, its climate is of the Mediterranean sub-arid type; the average winter rainfall is 300 mm and the mean annual temperature 19°C, but winter frosts are no exception there and in summer the temperature frequently exceeds 40°C; thus the climate, despite the proximity of the sea, is markedly continental. Finally, the natural vegetation which at present covers this plain is a sort of steppe consisting essentially of wormwood (*Artemisia herba alba*), jujube (*Ziziphus lotus*) and plants belonging to the Salsolaceae family.

THE SOILS OF THE ZEBRA PLAIN

The Zebra Plain has been subjected to a detailed pedological survey, having been mapped to a scale of 1:20,000 with the co-operation of J. L. GEOFFROY and CH. MASSONI.

Within the framework of the French classification (AUBERT, 1963) the vast majority of soils found in this plain are brown isohumic sub-tropical soils, more or less ancient as determined usually by the age of the quaternary deposits on which they developed.

The principal physical and chemical characteristics of these soils are as follows:

Chalk content: nearly all the soils are strongly calcareous from the surface downwards; the content may be 10–25% in Horizon A. There is moreover nearly always a chalk accumulation horizon which usually begins at a depth of 40–50 cm. But this accumulation horizon varies enormously from one type of soil to the other; its thickness ranges from 30 to over 150 cm; its chalk content from 30 to 90%; the forms assumed by the chalk in this accumulation horizon are very diverse: spots, granules, nodules, incrustations, crusts, slabs.

Texture: sandy-argillaceous on the surface. But beginning from a depth of 30–40 cm and down to 100–120 cm these soils nearly always show a horizon that is definitely more argillaceous and rubefied: in this horizon the clay content may vary between 35 and 55%. The varieties found are generally illite, chlorite, a little kaolinite and here and there a little Montmorillonite.

Organic matter: these soils have a fairly low content in organic matter, but it is deeply distributed (isohumic distribution): there is 2–2.5% on the surface and 0.5–0.7% at a depth of 50 cm. This organic matter is in an advanced stage of evolution with a carbon/nitrogen ratio equal to or below 10.

Structure: polyhedric to nut-shaped on the surface, more or less fine, sometimes very fine polyhedric in depth, in the clay and chalk accumulation horizon, where the structure of these soils is very well developed. Their structural stability, however, is always very weak, especially in the B horizons; according to HÉNIN's (1960) method the instability indexes are 2–10 on the surface and 10–20 in depth.

Salinity and alkalinity: the Zebra Plain soils are to a very great extent salinated and alkaline. This salinity and alkalinity, however, is hardly ever apparent on the surface, but only from a depth of 30–50 cm and lower.

To take salinity first, the conductivities of horizons B and C oscillate between 8 and 25 mmhos; this corresponds to 3–10‰ total salts, which are essentially sodium chloride. Surface conductivity never exceeds 2–3 mmhos.

Now as regards alkalinity: one first finds that from the surface the soils show high pH figures: pH water 8.4–8.7 and pH KCl 7.4–7.6. Nevertheless despite these pH figures the surface horizons never contain more than 5% sodium on the absorbent complex. By contrast there is often much magnesium: 30% and more.

In the depth, starting from 30–40 cm, pH water is 8.5–8.6 when the soils are salty, but if salinity is low it oscillates between 9.0 and 9.5. Figures for pH KCl range between 7.7 and 8.2. On the adsorbent complex of these B and C horizons the sodium content frequently exceeds 10%, but this is not generally the case and it is not rare to find that for pH figures higher than 9 the adsorbent complex has a low sodium content. By contrast there is always much magnesium: 30–60%.

It should finally be stressed that there is at present no phreatic layer in the Zebra plain; thus the salinity and alkalinity of the soils originated either from ancient pedogenesis, or from alluvial and colluvial mother rocks that could have been deposited in a saline and alkaline condition.

THE PROBLEMS POSED IN RECLAIMING THE SALINE AND ALKALINE SOILS OF THE ZEBRA PLAIN

The soils of the Zebra Plain, strongly saline from a depth of 40–50 cm, are thus also strongly alkaline; it would appear, however, that this alkalinity, proved beyond doubt by the high pH figures, is not due only to the presence of sodium on the adsorbent complex.

In order to understand the causes of this alkalinity, we undertook detailed laboratory studies of the adsorbent complex, of the soil solution and of the chalk in these soils. Available space does not permit inclusion of details of the tests carried out and results obtained. Some of these results have already been published (RUELLAN 1963, 1964). We shall content ourselves with summarizing the essential conclusions as hereunder:

(1) The alkalinity of the soils of the Zebra plain may be due:

To the presence of small quantities of magnesium carbonate not exceeding 2–3%; we were able to verify several times that this factor alone could easily account for the existence of pH figures between 9.0 and 9.5;

To the presence of 10–15% of sodium on the adsorbent complex.

To the presence of both factors.

(2) It would seem on the other hand that the presence of large quantities of magnesium on the adsorbent complex in no way accounts for these high pH indexes.

Thus reclamation of the soils of the Zebra plain through irrigation poses a certain number of problems on the salinity and alkalinity plane.

First problem: that of washing away the salts, which must be eliminated to a depth of at least 1 m. Can this desalination be done easily and quickly? What method should be used?

Second problem: if this desalination is done too quickly, faster than dealkalization, will it not permit the dispersion of the alkaline clay, the destruction of this very unstable structure, the creation of an impermeable sub-superficial horizon? It should further be pointed out that alkalization is certainly not the factor responsible for structural instability; texture and organic matter also play an important role.

Third problem: is de-alkalization itself possible, since it requires diminution of the sodium percentage on the adsorbent complex simultaneously with diminution of magnesium carbonate percentage?

It is moreover indispensable to verify whether it is really necessary to eliminate this magnesium carbonate in order to secure worthwhile (vegetal) crops, i.e. is it really necessary, particularly with a view to improving the assimilation of mineral elements, to lower the pH of the soils to a figure near to 8.0?

Finally, a fourth series of problems: what irrigation methods, irrigation doses, fertilizers, cultivation techniques, vegetal yields should be applied on these soils – first to improve them and next to secure the best productivity from them?

TESTS CARRIED OUT AT THE EXPERIMENTAL STATION OF THE ZEBRA PLAIN

In order to study and attempt to resolve these problems as a whole, it has naturally been necessary to set up an experimental station, which has now been working for more than five years. Many results have already been obtained: in the following pages, after rapidly describing the water used for irrigation and the principal tests carried out, we shall sum up these results in the field of evolution of soil salinity and alkalinity.

The irrigation water

By means of two dams that great Moroccan river, the Moulouya, is used for irrigation of the Lower Moulouya perimetre.

The principal chemical features of this water are as follows:

Its salinity is not negligible, oscillating between 700 micromhos, a minimum which it attains at the end of the winter and 2,000 micromhos, a maximum reached at the end of the summer. This salinity is therefore fairly strong and in zones already under irrigation we often found considerable salt accumulations – up to 12‰ – at the top of the furrows. After a few years' irrigation, if no precautions are taken, soil salinity may attain 2 to 4‰ in the first 20–30 cm.

As regards the composition of this salinity, it is very favourable for the improvement of alkaline soils. Actually the principal characteristic of the Moulouya water is its high content in earthy-alkaline cations and sulphate anions. In milli-equivalents, the calcium percentage in relation to the cation total is most frequently around 40%; the figure for magnesium is 30% and the sulphate percentage in relation to total anions usually ranges from 40 to 50%. Chloride and sodium content is therefore always rather low, with the sodium adsorption ratio oscillating between 1.0 and 2.5. We may therefore describe the Moulouya water as "de-alkalizing." But for soil improvement in the Zebra plain it has one drawback: it is over-rich in magnesium and we were able to verify through laboratory and terrain tests that its use caused an increase of magnesium on the adsorbent complex of the soils.

Tests carried out

The following principal tests are already carried out or still under way at the Zebra Plain experimental station:

Soil desalination by the following two methods:

"Crash" desalination through irrigation in a very large single dose, and

Progressive desalination by washing at each irrigation.

Soil de-alkalization by the following methods:

Utilization of the Moulouya's waters only;
Surface application of solid gypsum;
Addition of gypsum in irrigation water;
Application of organic matter in the form of manure and green fertilizers;
Application of greatly diluted sulphuric acid in irrigation water.

Comparison between various irrigation methods and particularly between irrigation by sprinkling and gravitational methods of irrigation, as regards their action on the evolution of the physical and chemical properties of the soils.

Research in cultivation.

Finally, a variety of cultures are tested in order to study simultaneously their behaviour and their influences on the evolution of the soils. So far the following cultures have been effected: cotton, sugar beet, sweet pepper (*niora*), alfalfa, Alexandrine clover, turnip, sugar cane, potato, sunflower.

As a whole these tests are carried out on two of the plain's principal soil types: a deep-lying sub-tropical brown isohumic soil with very marked clay accumulation and in which chalk accumulates in the form of spots and granules, dosing only 25 to 40%, and a shallow sub-tropical brown isohumic soil in which the chalk accumulation, which limits depth starting at 30–50 cm, is a chalk shell 30 to 60 cm thick with a chalk dosage of 55–90%.

Finally, all these tests have always been preceded and accompanied by many laboratory tests.

Results obtained in soil desalination and de-alkalization.

(1) Desalination. This may on the whole be carried out easily and quickly.

On deep soils, we obtained the following results: By increasing irrigation doses 20–30% on the water requirements of the cultures, soil desalination to a depth of more than 1 m is effected in two years; salinity is stabilized at between 1 and 1.5‰, i.e. a conductivity of 1–2 mmhos; that is certainly the minimum conductivity which it is possible to obtain, in view of the salt content of the irrigation water.

This result may be secured more quickly by means of a 50% increase in the irrigation doses.

It is obtained immediately through application of a single irrigation dose of 5000 m^3/ha.

On shallow soils, despite previous breakage of the chalk shell, salt removal was shown to be definitely slower, particularly for encrusted horizons and for those situated under the shell. There is nothing surprising in this in view of the fact that in these soils the general permeability is fairly low and that water cannot circulate quickly except by way of the subhorizontal cracks of the chalk crust and the vertical cracks caused by breakage.

(2) De-alkalization. De-alkalization, that is lessening of pH figures to a level

around 8.0, naturally proved – in view of the causes of alkalinity – a much trickier job.

It is first of all necessary to stress a very important point: if the maximum desalination which could be obtained for a deep soil is definitely adequate to permit cultivation of most plants, even those which are very sensitive to salts, this desalination is nevertheless not total; and it is thanks to the preservation of a slight salinity, which prevented clay dispersion and subsoil impermeabilization, that sufficient drainage was maintained – a drainage that permitted the beginning of de-alkalization after most of the salts had gone.

As regards the deep-lying soils, the results which we have so far obtained are – briefly summarized – as follows:

(a) To *eliminate* the sodium from the adsorbent complex is an easy task. By simultaneous study of the evolution of the adsorbent complex and particularly of the evolution of the composition of the saturation extract, we were able to follow sodic de-alkalization very closely; without any soil improvement, one obtains in 18 months, through a 40% increase in irrigation doses, an almost total sodium elimination to a depth of over 1 m. This de-alkalization is accompanied by a slight improvement of the structural stability of the deep argillaceous horizons. One nevertheless finds that, despite sodium elimination, on the one hand, pH figures for horizons B and C remain high: 8.7 to 9.0; on the other hand, the sodium has been partially replaced on the adsorbent complex by magnesium; finally, the structural stability remains very weak.

(b) Surface applications of solid gypsum are almost entirely without effect; they dissolve much too slowly.

(c) Laboratory attempts to percolate the soils with gypsum-enriched Moulouya water showed that sodic de-alkalization is speeded up: there is nothing surprising in this.

There is a considerable desorption of magnesium: the desorbed quantities are noticeably greater than those which can originate from the adsorbent complex only, the gypsum therefore certainly causes a very slow dissolving of the magnesium carbonate; at the end of the experiment, the pH of the earth sample is 8.6–8.7, therefore inferior to that obtained after sodium elimination.

(d) On the terrain, adding gypsum to irrigation water has so far produced noticeably less significant results.

We successively added to the irrigation water 0.3 g/l gypsum, then 0.6 g/l, then 1 g/l. Yet despite precautions of all kinds the gypsum dissolves very badly and actually only very little, and especially reaches the experimental lots very irregularly. As a result, after four years of tests, the results are highly contradictory:

On some lots, pH figures actually fell to 8.6–8.7 according to the laboratory tests and cultivation yields improved fairly markedly;

On the other hand, on other lots no difference was apparent between the control lots and those irrigated with gypsum-treated water.

Anyway this method does not seem to provide the solution: it is expensive and complicated, as against increases in yield that remain mediocre. We are nevertheless continuing the tests.

(e) In the laboratory we have also tried much diluted sulphuric acid. The results are definite: percolation of a sample of earth alkalized with Moulouya water to which is added 0.5 or 0.2 g/l of sulphuric acid causes rapid dissolution of the magnesium carbonate and one pretty quickly gets pH figures of 8.2–8.4 which are more or less normal for calcareous soils.

(f) On the terrain, irrigation tests with water containing 0.2 g/l of sulphuric acid have only just started. We therefore have no results to give. As it seems to us, however, the results of this experiment may be expected to condemn this method. In fact the use of sulphuric acid, which presents many dangers, is very expensive, and it seems unlikely that the increase in the cultivation yields would be such as to cover the costs. It should in fact be stressed that the yields which we obtain at present are far from negligible: 1.5–2 t/ha for Egyptian cotton, 80–100 t/ha (in the green) for alfalfa; yet other cultures (particularly sugar beet) produce mediocre results and especially all cultures still produce very irregular results.

(g) Applications of manure on a considerable scale have so far produced no results either in the pH field or in yields. But it is certainly still too early to draw conclusions: the action of organic matter, if any, can only appear after a very long interval.

Thus if the desalination of the soils of the Zebra plain poses no problems and if on the other hand after five years' irrigation structural instability has not caused the impermeabilization of the subsoil, it appears by contrast that full de-alkalization is very difficult to obtain. But the problem must now be approached from a different angle: is such de-alkalization really indispensable? Would not other cultivation practices such as the application of organic matter, of mineral fertilizers in abundance, of oligo-elements, and choice of judicious crop rotation serve to counteract the harmful effects of these high pH figures? It is in this direction that we now propose to orientate our researches.

SUMMARY

The soils of the Zebra Plain are saline and alkaline from a depth of 30–50 cm. The soils under irrigation can easily be desalinated. Alkalinity, by contrast, which is due simultaneously to the presence of sodium of the adsorbent complex and to the presence of small quantities of magnesium carbonate, is difficult to eliminate. Thanks to the favourable composition of the irrigation water, which is rich in calcium sulphate, sodium elimination is rapid. By contrast, the dissolution of the magnesium carbonate, which is

slightly accelerated by adding solid gypsum to the irrigation water, is very slow, and one fails to get pH figures lower than 8.6. Only very strongly diluted sulphuric acid makes possible the attainment of a pH figure of 8.2; but this method seems too expensive. Anyway it is not certain that the elimination of magnesium carbonate is indispensable.

RÉSUMÉ

Les sols de la plaine du Zebra sont salés et alcalisés à partir de 30–50 cm de profondeur. Le dessalage des sols, sous irrigation, est facilement réalisable. Par contre, l'alcalisation, qui est due à la fois à la présence de sodium sur le complexe adsorbant et à la présence de faibles quantités de carbonate de magnésium, est difficile à éliminer. Grâce à la composition favorable de l'eau d'irrigation, riche en sulfate de calcium, le départ du sodium est rapide. Par contre, la dissolution du carbonate de magnésium, qui est légèrement accélerée par l'apport de plâtre dans l'eau d'irrigation, est très lente, et on n'arrive guère à obtenir des pH inférieurs à 8.6. Seul l'acide sulfurique très dilué permet d'atteindre un pH de 8.2; mais c'est une méthode qui semble trop coûteuse. De toutes façons, il n'est pas certain que l'élimination de ce carbonate de magnésium soit indispensable.

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