Saline Soils of the Senegal Delta

J. H. DURAND

Institute de Recherches Agronomiques Tropicales, Seine, France

The Senegal delta presently occupies a territory roughly in the shape of a right isosceles triangle with its hypotenuse between Saint-Louis and Richard-Toll, the two equal sides being the sea on the West and the 16° 35' N parallel on the North. Old deltaic formations extend up the valley to the surroundings of Boghé, 250 km from the coast.

Soil deposition

The setting up of the delta material started at Nouakchottien (this is a local name of deposits that were formerly attributed to Ouljien, but their C14 dating shows them to be about 5500 years younger than Ouljien) with the deposit of a marine terrace which extends to Boghé.

Later deposits, called post Noaukchottiens, include a fluvio deltaic complex forming embankments of plane surface mixed with fluvial deposits in the valley and accompanied in the present delta by littoral strands from North to South. The latest of these, the Barbaric tongue, has shifted the mouth of the river southwards. Recently basins, salty or not, have formed and towards the river mouth, mud-holes, slikkes and schorres have developed.

Climatology — Hydrology

The climate in this area is quite variable. The average yearly rainfall in Saint-Louis is 388.8 mm, 362.3 of which falls between July and October. The average yearly temperature is 24.7°C with a minimum of 21°9 in January and a maximum of 28°3 in September.

The hydrology of the area is totally conditioned by flood. Around March, the flow of the river Senegal is not sufficient to balance evaporation, the sea invades the river and salty water reaches Dagana. When the flood occurs, at the end of July or early in August, it pushes back the salty water. The water level rises and invades the "marigots". This finally discharges into the basins. Only N'Thiagar basin was safe from this flooding because of the height of its sill. The soft water, coming later, adds to the salty water.

In order to create a soft water reservoir for Saint-Louis, the Gorom sill was raised and a dam was built at Boundoum. The result was that the basins situated South-East from that "marigot" were flooded with soft water.

Mud-holes, slikkes and schorres are under tidal influence and are periodically invaded with sea-water.

Origin of the salts in the materials

The Senegal delta is invaded periodically by salty water in some tide-channels, mud-holes, slikkes, schorres and basins. This invasion is caused either by the tide or by the flood. Thus the salts that impregnate the alluvium originate from the sea and are deposited by periodical flooding with salty water. The composition of the salts is related to that of the salts in sea-water. They contain sodium chlorides and sulphates, the latter in relatively large quantities. These sulphates and organic sulphur compounds of plant or animal origin undergo biological transformations that characterize the soils of this delta and more generally of the basins.

Transformations of the salts in the alluviums

Organic sulphur is mineralized by many heterogenous, non specialized bacteria. Generally, hydrogen sulphide is the predominant product. Mercaptans, metalloidic sulphur and some oxidised sulphur also occur. Under anaerobic conditions, hydrogen sulphide is the dominant product of decomposition.

The main source of sulphur is the sulphates from the sea. These sulphates are reduced into sulphides by autotrophic bacteria according to the following reaction:

$$SO_4^{=} + 4\,H_2 \rightarrow S^{=} + 4\,H_2O + 60\ \text{Cal.}$$

with, as intermediary products sulfites, thiosulphates, tetrathionates and sulphur. In the presence of organic products, the heterotrophes act faster giving the same products. Lastly, a fungus may produce mercaptans as an intermediary product.

The first step of sulphide oxidation is a chemical rather than a biological phenomenon although some bacteria may sometimes occur at a second stage. Chemical stage:

$$H_2S + 1/2\,O_2 \rightarrow S + H_2O + 41\ \text{Cal.}$$

Biological stage, S is fixed in the cells and oxidized.

$$S + 1/2\,O_2 + H_2O \rightarrow H_2SO_4 + 118\ \text{Cal.}$$

These phenomena are limited.

Thiobacillus, a group of autotrophic, specialized bacteria can oxidize the sulphides into sulphates with a high yield, according to the following ideal scheme:

$$HS^- \rightarrow S \rightarrow S_2O_8 \rightarrow S_4O_6 \rightarrow 2\,H_2SO_4$$

$$Na_2S_2O_3 + 2\,O_2 + H_2O \rightarrow Na_2SO_4 + H_2SO_4$$

$$2\,Na_2S_4O_6 + 7\,O_2 + 6\,H_2O \rightarrow 2\,Na_2SO_4 + 6\,H_2SO_4$$

The soil, then, becomes very acid. The sulphur of proteidic origin is mineralized, the final product being hydrogen sulphide, which is clearly predominant, accompanied by mercaptans, metalloidic S and more or less oxidized S.

At this stage a certain number of secondary reactions occur due to the simultaneous presence of sulphuric acid and sulphides or a little oxidised sulphur.

On the presence of water soluble sulphides there may be a liberation of hydrogen sulphide. If sulphuric acid is sufficiently concentrated, there may be, in addition, formation of sulphur dioxide and a precipitation of white colloidal sulphur.

With sulfites, there is a characteristic production of sulphur dioxide while with the hyposulfites there is a precipitation of yellow sulphur.

These reactions, may be simultaneous in the same profile and frequently there is a production of hydrogen sulphide or sulphur dioxide or both, while the channels left by the roots become covered with white or yellow products.

Finally, the acidification of these soils, the pH of which may fall below 3 (pH under 2 is common), is accompanied by the liberation of alumina, which is very toxic to crops.

Pedological consequences

Different reactions will happen depending on whether the sediments contain limestone or not.

In the presence of limestone, the acids that have been formed are neutralized. The reactions are further complicated by the presence of iron clay.

In the presence of iron, sulphides are formed according to the reaction:

$$2\,Fe\,(OH)_3 + 3\,H_2S \rightarrow FeS_2 + S\,Fe + 6\,H_2O$$

the soil then is black, and slightly acid or neutral.

By oxidation, the following reaction takes place:

$$2\,FeS_2 + 7\,O_2 + 2\,H_2O \rightarrow 2\,FeSO_4 + 2\,H_2SO_4$$

with H_2SO_4, $FeSO_4$ makes ferric sulphate:

$$2\,FeSO_4 + H_2SO_4 + O \rightarrow 3\,Fe_2\,(SO_4) + H_2O$$

This ferric sulphate is then hydrolysed:

$$3\,Fe_2\,(SO_4) + H_2O \rightarrow 2\,FeSO_4\,(OH) + H_2SO_4$$

and sulphate accumulations appear in the form of $x\,Fe_2O_3$, $y\,SO_4$, $z\,H_2O$ which are localized in the former root channels and on the face of the aggregates and characterize the sulphate soils (alum. soils). At this stage the soils present straw-yellow strains of these sulphates and white colloidal sulphur and often, bright yellow points of metalloidic sulphur.

The hydrolysis then can continue with sulphuric acid being set free.

$$FeSO_4\,(OH) + 2\,H_2O \rightarrow Fe\,(OH)_3 + H_2SO_4$$

The yellow specks disappear and the soil becomes very acid.

The sulphuric acid thus freed causes the removal of the bases from the adsorbing complex and reacts on the clay minerals in the soil according to the general scheme:

$$x\ Al_2O_3\ y\ SiO_2 + 3\ H_2SO_4 \rightarrow 3\ Al_2(SO_4) + \text{hydrated silica.}$$

Combining with the soil sulphates, the aluminium sulphate gives aluminium which is the final product of the complex process.

In the soils, the type of salinization is usually characterized by the ratios: $\frac{SO_4}{Cl}$ and $\frac{Ca}{Mg}$. The described processes modify these ratios which should, like the sea, have values close to 0.1 and lower than 1 respectively.

The reduction of the sulphates causes a lowering of the ratio $\frac{SO_4}{Cl}$ and may even bring it down to zero if all of the sulphates are reduced to sulphides. The reaction of the medium may not change much or the pH may be slightly lowered. Later, when reoxidation occurs, the $\frac{SO_4}{Cl}$ ratio will again rise while the pH will be greatly lowered if the sulphuric acid formed is not neutralized by limestone.

In the presence of limestone, the sulphuric acid is neutralized and the pH remains above 7, but the $\frac{Ca}{Mg}$ ratio, which is under 1 in the sea, rises and clearly goes above this value. Little by little, the limestone disappears from the soil. One may then presume, that a $\frac{Ca}{Mg}$ ratio, higher than 1, even if limestone be absent from the soil, is a probable indication of its presence in the original material.

Later, if the oxidation-reduction processes go on, everything will happen as with a non calcareous material. The only possible evidence of the former existence of limestone is a high value of the $\frac{Ca}{Mg}$ ratio. It is not preposterous to think that the abundance of gypsum which can be observed in some basins is related to such phenomena.

Attempt at classification

The saline soils in the Senegal delta belong to 2 groups:

Soils of parallic basins,

Soils of the edge of parallic basins.

The latter group form a transition towards the solonchaks and include the same subdivisions as the former.

The values of the ratios: $\frac{SO_4}{Cl}$ and $\frac{Ca}{Mg}$ allow the subdivision into 4 sub-groups:

Sub group 1 — Modal $\frac{SO_4}{Cl} > 0.1$

subdivided into 2 families.

1.1 — Non calcareous sulphate soils $\frac{Ca}{Mg} < 1$ and $pH > 5$ formed on non calcareous materials.

1.2 — Calcareous sulphate soils $\frac{Ca}{Mg} \geqslant 1$ and $pH > 7$ formed on calcareous materials.

Sub group 2 — Reduced: The sulphates have been transformed into insoluble sulphides and $\frac{SO_4}{Cl} < 0.1$. This ratio may even be zero if all the sulphates have been reduced.

It is sub divided into 2 families:

2.1 — Reduced sulphate soils $\frac{Ca}{Mg} < 1$ and $pH > 5$

2.2 — Reduced calcareous sulphate soils $\frac{Ca}{Mg} \geqslant 1$ and $pH \geqslant 7$

Sub group 3 — Re-oxided $\frac{SO_4}{Cl} > 0.1$.

Theoretically this group includes 4 families:

— a family of sulphate soils with a $pH > 5$. If the formed sulphuric acid has been eliminated, it is the family of non calcareous sulphate soils which has already been included in sub group:

3.1 — Acid sulphate soils $\frac{Ca}{Mg} < 1$ and $pH < 5$ and may be even below 2 because of the formation of free sulphuric acid.

3.2 — Decalcified acid sulphate soils with $\frac{Ca}{Mg} > 1$, indicating the presence of limestone in the original material, and $pH < 5$.

3.3 — Decalcified sulphate soils $\frac{Ca}{Mg} > 1$ and $pH = 7$, with a limestone residue.

Sub group 4 — Polygenic. The soils of this sub-group have been subjected to several cycles of reduction and oxidation which finally resulted in soils that may not be classified in the first 3 sub groups. Usually they are not recognizable either by chemical or visual examination.

The case of the Senegal delta

All of the soils mentioned in the above classification can be found in the Senegal Delta. The most common however, are the acid-sulphate soils. These soils are found in all the deltaic formations. However, they show many differences due to the flooding regime which results from their topographic position.

The most important difference between the soils of the low and the high zones is their texture, respectively very fine and medium. A second difference is the dark or very dark colour of the low zones and light colour of the high ones. The periodic flooding of the low zones sustains an intense microbiological life which renews the biological phenomena described above. In the high zone, these biological reactions are limited and the salinity and acidity of the soils are but an inheritance of their past. Moreover, there is in the soils of the low zones a very salty water table.

Agronomical consequences

The soils that continue to be subjected to flooding by salty water do not evolve, at least from the point of total salinity. The only transformation which they are subjected to is cyclic, the salty water increases their pH, the sulphates which they contain are reduced, and after the withdrawal of the waters, are reoxidized with a new decrease in pH. One can think of their reclamation only after the salts, the acidity and the toxic products have been eliminated.

The formerly salty basins that were free from salty water at the beginning of the century can now be put under rice cultivation. Results obtained in Casamance show the means of reclaiming the delta basins, even if they are clayey.

In Casamance, rice is grown in the clayey mangroves. It is transplanted in ridges after the irrigation water has sufficiently washed the salt out of the soil. The yields obtained are on an average one and a quarter ton per hectare.

Irrigation and drainage in the higher areas would allow the production of food or truck crops if drainage is satisfactory.

Conclusions

The salts that impregnate the alluviums of the Senegal delta may be of old origin in the higher areas or may be periodically renewed in the lower zones. These salts were, or are each year, subjected to a series of biochemical transformations leading to their acidification.

Presently, the soils of the basins, including those of the clayey basins can be used for rice growing if the necessary work is done. Those of the higher areas can be irrigated and drained to eliminate soluble salts. They can then produce good food or truck crops.