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Etude hydro-agricole du Bassin
du Fleuve Senegal

Mission report of
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March 1969

Contents

I. Introduction

Time schedule

February 10 : leave for Rome; discussions at headquarters with Messrs. Grehan and Ambroggi.
" 11 : leave for Dakar
" 11 to 25 : St.Louis
" 26 : leave for Rome; discussions with Messrs. Grolee and Grehan
" 28 : leave for Amsterdam

The terms of reference were: to consult with the Project Manager on drainage problems in the Delta Region of the Senegal River with a view to agricultural development.

The drainage and related problems were discussed with Mr. Grolée - project director, Mr. Moussu - consultant for hydro-geology, Mr. Thirion - soil scientist and Mr. Audibert - hydro-geologist. Furthermore, with the directors

and staffmembers of IRAT [1] and SAED [2], notably with Mr. Trang Minh Duc - IRAT ingénieur de génie rural.
All of them have been of great help by supplying information whenever needed, making documentation available, participating in field trips and experiments.
Many thanks are due to Mr. Audibert for the perfect way he has organized so many things.

Since technical expressions in the drainage language are interpreted in various ways, the meaning attached to some of them in this report are stated below:

drainage : Fr. drainage: tout processus d'évacuation d'excès d'eau vers des canaux ou des tuyaux, que ce soit par la voie superficielle ou souterraine.

surface drainage : Fr. drainage superficiel : l'évacuation de l'eau par dessus la surface.

deep drain : Fr. drainage profond ou drainage souterrain: l'évacuation à travers le sol, soit par la couche supérieure soit par le substratum, au moyen de canaux ouverts, de tuyaux (ou d'une combinaison des deux).

drain (or field lateral) : Fr. drain : moyen de drainage quelconque (canaux, tuyaux)

tube drain : Fr. drainage par tuyaux: drainage profond effectué par des tuyaux.

collector drain : Fr. drain collecteur : canal ou tuyau de grand diamètre recevant l'eau de drains d'un ordre inférieur.

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1) Institut de Recherches en Agronomy Tropicale. IRAT conducts investigations into the possibilities of growing sugarcane in an experimental area of 120 HA. Drainage constitutes one of the problems under investigation. Open and closed drains have been constructed at depths of 1.30 m and 1.80 m, spacings are basically 50 m and 100 m. Watertable observation wells and piezometers have been installed and are regularly observed since 1968. Drain outflow has been measured as well, but less frequently.

2) Société d'Aménagement et Equipement du Delta. SAED recently established the Station Expérimentale de Cultures Industrielles de Kassai - Sud. Tomatoes and beans have been planted for the first time in 1968. The fields do not have a sub-surface drainage system, the soils were not salty. Watertable fluctuations are being measured.

II. General observations, conclusions, recommendations

II.1. At the request of the Project Director attention was concentrated on the delta region. In this area problems of salinity and drainage are clearly present, whereas - reportedly - this is presently much less so in major parts of the valley. It will be useful, however, to continue and intensify the observation of the movement of shallow groundwater tables in the valley in the course of irrigations. Insufficient natural drainage may cause the latter to rise gradually. Salinity in the upper soil layers may be indicative of poor drainage conditions.

It is understood that "fresh" water will be basically available to all parts of the delta region. As a consequence, the location of soils has not constituted a criterion in the present report.

II.2. Amongst the various geo-genetic types of the Delta region, two of them seem to be of major interest: the soils of the flat, low-lying "cuvettes" and those of the slightly higher elevated "fluvio-deltaic" soils.
The latter - reportedly - are highly heterogeneous, stratified (with tilting layers), their hydrological properties being quite variable and hard to assess.
The cuvettes, on the contrary, are more homogeneous: there usually is a clay cover - often having the capacity of swelling and shrinking - of varying thickness (20 cm to over 1 m) which overlies a medium textured layer of more than 1 m in thickness. The latter is reported to be underlain by poorly pervious clay layers.
The cuvette soils in particular have been the subject of discussion during the mission. This does not necessarily mean that the fluvio-deltaic soils are considered of less favourable quality. Since their properties will vary from one place to another, however, they are to be studied in a rather pragmatic way.

II.3. The possibilities of supply of water to and discharge from the rootzone of the plants, which include those of maintaining a favourable salt balance, will be governing the permanent successful cultivation of the soils.
Concerning irrigation, present cultivation schemes of IRAT and SAED indicate that at least part of the soils is irrigable. Though mainly rice

and sugarcane are grown - the latter being remarkably resistant to submergence - there is reason to believe that other crops could be irrigated as well if adequate supply systems are applied.
The conditions of drainage would seem more complicated. Hydrological aspects in general have received relatively little attention in studies elsewhere on the problems of swelling soils. Much is still unknown; ideas expressed below, therefore, will need to be verified by investigations and experiments.

II.4. The drainage problems have been examined on the following general basis, reported by the hydro-geological section:
- there is no natural drainage
- the phreatic reservoir is not fed by seepage inflow
- precipitation does not have any considerable influence on the drainage systems to be constructed.

The general fluctuation of the groundwater table in the course of the years - within the upper 2.5 m of soil - would seem to confirm these conditions

II.5. Normally, in areas where these conditions hold true and where irrigation is introduced, the construction of a sub-surface drainage system is coupled to that of the irrigation system, right from the start. The reason is that, without drainage, the water table would rise into the rootzone due to:
- unavoidable irrigation losses, notably field application losses. An important part of the latter are deep percolation losses which will join the phreatic reservoir;
- the volume of water that should percolate the soil rootzone in order to maintain a favourable salt balance.

Note: initial leaching during reclamation stages will have no special consequences for the drainage system as explained in section III.

There is no reason to adopt a different line of thinking for the soils under consideration.

II.6. Can the delta soils be drained?

The answer depends largely on the permeability of the various soil layers. It appeared that, in parts of several cuvettes visited, the thickness of the clay cover is less than 50-60 cm. Fissures and cracks extend easily till this depth, i.e. till the medium textured subsoil. As a consequence, irrigation water will fill up the cracks in the first stage of watering and will then move on downward into the subsoil as long as the swelling clay permits and water continues to be supplied. Since much salt is found at the walls of cracks, this process is considered to contribute substantially to the required leaching.

There are several indications that the subsoil layer is capable of transmitting water. Measurement with the "augerhole method" in the 120 HA - IRAT area showed a permeability of about 1.5 m per day, which is to be considered fair. Such soils are considered relatively easily drainable, and thus, leachable.

In areas where the swelling clay extends downward till greater depths (over 1-2 m), the subsoil is likely to be poorly permeable. If so, these soils will be hard to drain and, as a consequence, hard to cultivate permanently.

There are, naturally, a number of other profiles, which are found more or less between these two extremes. Their practical drainability depends largely on the thickness and nature (montmorillonnite or non-swelling mineral) of the clay cover and - furthermore - on the permeability and thickness of the underlying layer.

II.7. In view of the importance of adequate water management in the various types of profiles, it is suggested to classify the soils on the basis of their water transmitting and other physical properties in hydro-pedological units. The sub 6 indicated types of profiles are likely to constitute such units. Soils of one unit will need similar water management - notably drainage - systems.

Criteria for the hydro-pedological classification are presently largely lacking. They will have to be developed through investigations and experiments. Qualitatively, the criteria relate to:

- the capacity of the topsoil and rootzone to absorp water sufficiently rapidly.
- the possibility of water to seep through the rootzone into the subsoil at a sufficient rate
- the transmissivity of subsoil and deeper strata
- salinity and alkalinity
- specific phenomena of swelling clays

In section IV, the programme, more is said about some of these criteria.

II.8. The type of drainage system needed depends on the path taken by excess water on its way to an outlet, This path, in turn, is closely linked to the (relative) permeability of upper and deeper soil layers.

During the initial part of an irrigation some water will percolate below the rootzone, i.e. - say - below a depth of 50 cm, and will cause the water table to rise. After a short period of time - 15 to 60 minutes - deep percolation rates reduce to low or very low values as a result of swelling. A perched water table is likely to develop in the upper 50 cm of soil (Fig.1).

The drainage problem, then, may be considered to consist basically of three parts:

a) keeping the watertable fluctuation between fixed limits by the construction of a deep drainage system.
b) lowering and removing of the perched water table in the soil rootzone by a shallow (sub-surface) drainage system.
c) draining excess irrigation water at the ground surface (surface drainage system).

The field laterals of the deep system in soils having permeable substrata are thought to be at a depth of not less than 1.50 m. Collector drains will then have to be at least 2 m deep.

The required spacing of the field laterals can not yet be assessed. A great deal of information has been collected on the IRAT-experimental plots; much of it has contributed to the ideas expressed in the present report. A quantitative evaluation of the data, however, is complicated by a number of phenomena the nature of which will have to be determined by a few additional observations and verifications - see section 4, the programme.

In spite of these complications, the required drainspacing is believed to be fairly wide in soils having a medium textured, well permeable subsoil (see section III-4).
In deep swelling clay soil , on the other hand, the transmissivity of the substrata may be small enough to make spacings narrow and, thus, costly.

Collector drains which, preferably, are open ditches will need a spacing of 200 m or 400 m - allowing for field drains of 1 x 200 m and 2 x 200 m length respectively (Fig.2). These distances are governed by practical lengths of draintube lines which run between collectors. Further considerations of open and closed field drains and collectors are presented in section III-4.

Note: tube drains, installed in part of the IRAT plots, do not appear to function well at all times. This may be caused by mica-containing sand which has been used as a filter material. Anyway, it does not necessarily mean that tubedrains should no longer be considered for these types of soil.

The shallow sub-surface drainage system, needed to evacuate perched water, would have to consist of draintubes at about 60 cm depth and probably at spacings of not more than 10 m. The "backfill" in the drain trenches would have to consist of well permeable material. Such a system will be extremely expensive.
It is suggested that first the possibilities are studied of adjusting the irrigation methods and practices to the specific features of swelling clays. By doing so, one might succeed in keeping perched watertables low. In that case, strong evaporation and some slow seepage may cause air circulation soon after irrigation to be sufficient to avoid seriously reduced yields.

Surface drainage systems are closely linked to irrigation methods, land preparation, etc.; there is no need to discuss them here.

II.9. As has been indicated earlier, it is expected that part of the soils in the delta can be drained relatively easily. Since the movement of soluble salts is governed by water movement, the maintenance of a favourable salt balance in the rootzone of these soils will not create special problems. There are also soils, however, which would seem to be poorly permeable and hard to drain. The problems are still more serious when these soils contain considerable amounts of salts and need to be reclaimed by heavy leaching, whether or not combined with the application of chemical amendments.

It is suggested that, for the time being, investigations are concentrated in the first place on the "easy soils". The drainage - and reclamation - of the salty deep clay soils, which will require a considerable extra effort, and investment, might be left to a later stage. Non-salty deep clays, in the meantime, could be used for rice cultivation and. to some extent, for sugar cane.

The programme suggested in section 4 provides for a survey of hydro-pedological units, the results of which will show the location and acreages of "easy" and "difficult" soils.
In the meantime the problems of both types will need to be more clearly defined and basic solutions for salt and water control are to be found by means of continued investigations and experiments. To that end, some suggestions have been made in the second part of section 4; they are largely based on the work that has been done already by IRAT.

III. Nature of drainage problems and solutions

III.1. Basic conditions, general line of thinking

The hydro-geological investigations carried out so far show that there is no natural drainage nor seepage inflow of any importance into the phreatic reservoir.
Furthermore, it is assumed - for the time being - that rainfall will have no considerable influence on the drainage system.
It follows, then, that irrigation application constitutes the only source of excess water.

Irrigation is always coupled with unavoidable overland and deep percolation losses and, furthermore, with the need for leaching down the salts brought with irrigation water.
Overland losses will have to be evacuated by surface drainage systems, downward losses by sub-surface systems. The latter, of course, are needed only when natural phreatic levels are already so high that deep percolation losses will soon cause the watertable to rise into the rootzone of the crops. Indeed, phreatic levels in the non-irrigated lands of the delta are usually within the upper 2-3 m of soil. Supposing that there are no continuous flow barriers between rootzone and phreatic level, there is no doubt that a deep drainage system will be required to effect a favourable water and salt régime.

The path taken by excess water on its way to an outlet is governed by the permeability of the various soil layers.
Irrigation application efficiencies for salts of fair infiltration rate and permeability are usually in the range of 50-70 %. This means that 30-50 % of the applied water will have to be evacuated. If, e.g. the consumptive water use of a crop is 100 mm in 15 days, and the application efficiency is 70 %, then about 40 mm must be drained each 15 days (neglecting storage aspects). Part of it may be termed surface waste, another part will move downward into the subsoil, join the phreatic reservoir and cause its level to rise.

If the latter deep percolation losses would be in the order of 75 % of the total losses, i.e. 30 out of the above 40 mm, and the effective porosity (part of the soil which releases or takes up water when the water table is lowered or raised) is 5 % on a volume basis, the watertable will rise by 60 cm during water application. A deep drainage system, then, is needed to keep the watertable fluctuations between fixed limits of, say, 1.0 and 1.6 m below ground surface. The question remains as to whether such losses may be counted as effective in leaching soluble salts from the soil rootzone. In any case one will have to decide whether the required leaching or the unavoidable irrigation losses will govern the drainage criteria.

Before applying this type of reasoning to the delta the following brief observations on its soils need to be made.

III.2. The soils

For a general description of the soil formation processes reference is made to the hydro-geological and soil survey reports. These reports suggest that the following two geo-genetic types are of primary importance: the flat and low-lying "cuvette" soils and the slightly higher elevated "fluvio-deltaic" formations.
The latter, reportedly, are very heterogeneous, their profile in the upper few meters of soil consisting of clayey and lighter textured materials in various (tilting) layers. Their physical and hydrological properties, which are presently unknown, are likely to vary from one place to another. This means that experimental fields will be needed to judge the watermanagement possibilities.
It would seem useful to await the results of the reconnaissance soil survey before examining these characteristics in greater detail. Only then it will be possible to judge whether the results of investigations, conducted in small experimental units can be applied to larger areas.

The cuvette soils appear to be more homogeneous, easier to classify and locally obtained solutions are likely to be applicable to other regions of the delta. The upper soil layer is a heavy clay, dark coloured, of a massive structure, well cracked and fissured (when dry) till a depth of at least 50 cm. Its thickness varies from some 20 cm to over 2 m. These fluviatile clays often have the capacity to swell and shrink due to the presence of montmorillonnite. It is not yet clear whether all clays are of the same swelling type.

The heavy clays, if not too thick, are usually underlain by lighter textured stratified soils : thin layers of loamy sand, interchange with sandy clays, clayey sands and silt loams. The sand sometimes contains mica. The thickness of the lighter textured stratum is variable, but - reportedly - does not exceed some 2 m on the average. Underneath, layers of heavy and poorly pervious soils are found,

The salt content of the cuvette soils is now high, then low. The amount of sodium adsorbed to the soil complex is not yet well known; it appears to be variable as well. Not much information is available now on the physical reaction of the soil following water application for leaching.

III.3. Water transmitting properties of the soils

Experiments on the IRAT and SAED plots show that at least part of the soil is capable of absorbing water at a practical rate.
The fissures and cracks cause the infiltration rate to be high during the first one hour or part of it. In this small period of time some 50-100 mm of water may be absorbed by the upper 40-60 cm of soil. The infiltration rate, due to swelling, will then drop rapidly to low or very low values and a perched watertable is likely to develop.

Where the clay cover is thin, water will percolate into the lighter textured subsoil - especially during the initial stage of wetting - and cause the watertable to rise. There are several indications that this happens indeed and, as a consequence, that the medium textured subsoil is capable of transmitting water. Water levels in deep piezometers - having filters at 1.50-2.00 m depth - react upon irrigation. In some cases watertables rise by over 50 cm and drop gradually till the next application.
Earlier hydro-geological investigations show that groundwater tables rose as a result of floodings. It is true that, on the IRAT-plots, not all piezometers reacted well. This may be due to blocked filters, small water volumes applied as happens with sprinkling, poorly pervious subsoil etc., factors which will need to be closely examined.

The permeability of the medium textured subsoil was measured in four auger holes, three of which were made in the bottom of a dry ditch. Observation of the rising waterlevel in the auger hole was started as soon as water entered the hole (so-called direct augerhole method). All permeability values were between 1.0 and 1.8 m per day, which is to be considered fair.

There is, of course, no guarantee that all medium textured layers will be permeable or will have the same permeability. The present soil survey, combined with measurements of the permeability in the subsoil will have to show what variations are to be expected and where.
It is noted that some sandy layers are probably poorly permeable due to the presence of mica. Since mica containing sand has been used as a drainpipe-cover material, the (probably) poor functioning of the drains may, at least partly, be caused by a high drain-entry flow resistance. If this would be true, one will find frequently waterlevels in the drain trench which are above the level of the drainpipes.

The subsoil does not always consist of medium textured soils. Sometimes the heavy clay layer extends downward to over 1 m, and even till over 2 m. The water-transmitting properties of such profiles will depend on the type of clay mineral and, furthermore, on soil formation processes. The permeability may be expected to vary considerably from one place to another.

III.4. Basic drainage solutions

Since natural drainage, precipitation and seepage inflow into the soil rootzone are considered to have no considerable influence on the drainage system (III.1), the problem - in fact - is one of evacuating excess irrigation water and/or the volume of water required for leaching.

During the initial stage of wetting, some water will percolate below the rootzone, i.e. - say - below a depth of 50 cm. After a short period of time - 15 to 60 minutes - deep percolation rates reduce to low and very low values as a result of swelling. A perched water table is likely to develop in the upper 50 cm layer (Fig.1).

The drainage problem, then, may be considered to consist basically of three parts:

a) keeping the watertable fluctuation between fixed limits by the construction of a deep drainage system (sub-surface drainage).
b) lowering and removing of the perched watertable in the soil rootzone by a shallow drainage system (interflow).
c) draining excess irrigation water at the ground surface (surface drainage system).

Deep drains

The depth of these drains depends on the permissible watertable position and on the permeability of subsoil strata.
If the soil layer at 1 m depth would be impermeable, drains should not be installed at depths exceeding some 1.25 m.
In case there are no flow barriers at short distances below the rootzone, the watertable should not be permitted to rise above the level of 1.0-1.2 m below groundsurface. This is a rule of the thumb, holding true of "average" conditions after several years of cultivation. In case capillary flow is expected to be considerable, and the groundwater to remain salty for a long period, watertables are preferably kept below a depth of 1.50-1.80 m.

In view of the vertical and horizontal cracking in the upper clay layer, it is supposed that capillary transport in the underlying layer will have no great effect on the former. Therefore, for the time being, the watertable will be allowed to rise to the 1 m level. This level will be attained after irrigation in a peak season. The required watertable before irrigation depends on the volume of deep percolation losses.

Deep percolation losses are assumed to be smaller than is usually found on non-swelling, permeable soils. If the usual losses are set at an average of 1 to 3 mm per day, then the losses in swelling clays will not probably exceed a rate of 1 mm per day (approx. 0.12 l/sec/HA).

From a salt balance standpoint (i.e. prevention of re-salinization) it would seem logical to take into account a leaching volume of not more than 10 % of the total water volume applied. This figure is based on good quality irrigation water - 400 micromhos/cm - a maximum permissible soil salt content of 6 millimhos/cm (saturation extract), and a leaching efficiency factor of 0.3.

When the annual volume applied to the field is 2000 mm, the annual leaching requirement will not exceed 200 mm, and will probably be found somewhere between 100 and 200 mm.

As a consequence, it is unlikely that the required leaching would exceed the normal deep percolation losses below a depth of some 50 cm. It would be best, therefore, to keep in mind a design rate of sub-surface field drainage of 1 mm per day on the average and - in the meantime - try to obtain better information on the leaching efficiency.

Note:

1) When the soil is salty and has to be leached before crops can be planted, much more water will have to percolate the rootzone. This reclamation process has not been taken into account in the above estimate of design discharge. Firstly, because watertables during a reclamation stage are allowed to rise much higher than during cropping later on. The discharge rates, then, will be higher as well and may be in line with the maximum percolation rates which are possible in a swelling soil. Secondly, it seldom pays to construct a special drainage system for a brief period of reclamation. Lastly, salty swelling soils are usually hard to leach; as long as there still are non-salty, or only slightly salty soils, it would be better to bring the latter under the plough first and leave the difficult soils to later stages. In the meantime there will be time enough to study their specific characteristics and the ways of tackling them.
2) A maximum permissible soil salinity of 6 mmhos/cm (paste saturation extract) is a value often applied to crops which are not extremely sensitive to salt, growing on soils which are irrigated in a normal way. It may be desirable for swelling clays to let the soil dry out further than is normally practised, in order to let the soil crack again. In that case somewhat lower values may have to be applied.

A design discharge of 1 mm per day on the average, as indicated above, means that during irrigation on a 15 days basis, some 15 mm of water will percolate downward in the profile. Taking a low effective porosity (see III.1) of 4 %, the watertable will rise by 35-40 cm on the day of irrigation. If the higher watertable allowed after irrigation is at a depth of 1 m below surface (see above), then the watertable before irrigation will have to be 1.35-1.40 m deep.

In conclusion, in soils where the above reasoning holds true - and this is expected to be so when the swelling clay of no more than 50-60 cm thickness overlies a permeable substratum - the drains should be at least 1.50 m deep, i.e. the centre of draintubes or the waterlevel of ditches should be at that depth.
The required spacibg cannot be estimated as long as the aquifer transmissivity is unknown (permeability and thickness of water-transmitting layers below the swelling cover clay). An order of magnitude of drainspacing, however, is obtained by admitting a permeability of 1.5 m/day and an impermeable floor at 3 m below surface. The required drainspacing would then be about 70 m if drains are at 1.50 m depth and about 150 m with drains at 2.0 m deep.

The system of collector drains may consist of draintubes or open ditches, spaced at 200 m or 400 m. These distances are governed by practical lengths of draintube lines, which run between collectors (Figure 2). At 200 m collector spacing, chances are that no additional drains will have to be installed later on. If it appears later on that such drains would be needed, however, half of the number of collectors would no longer be needed (on the condition of flat land).
A drainspacing of 400 m is most likely to be inadequate. This means that collector drains, at this spacing, will have to be supported by field drains. The question remains as to what spacing will be required.

In sum, collectors at 200 m spacing may or may not effectuate adequate field drainage. If they do not, an overinvestment has been made in the system since roughly half of them will no longer be needed if additional field drains are constructed.
At 400 m spacing, no overinvestment will be made in the collector system. But field drains will be needed right away at spacings which cannot yet be estimated.
An intermediate solution might consist of collectors at 400 m spacing and closed draina at 200 m right away.

Note:
- in view of the possibility of additional drains later on, collectors should be open ditches. Poor soil stability, as observed in several places, may require relatively flat side-slopes and considerable maintenance cost.
- the normal waterlevel to be effected in open ditches is about 2 m below surface. Additional tube drains, having a length of 200 m and a slope of 15 cm per 100 m, and discharging at 20 cm above

ditch level, will run from a depth of 1.50 m to 1.80 m below surface, which satisfies the requirements discussed in the above.

- it will be possible to make field drains and collectors a little shallower, but this will result in narrower spacings.

Drainage of perched water

The drainage system needed to lower a perched watertable does not basically differ from the deep system. But the impervious floor is now at the shallow depth of 50-70 cm below surface and, consequently, there is no point in making the drains much deeper than that.
The deep drains are not expected to contribute largely to an effective control of a perched watertable because their spacing will be too large and, secondly, because there is no guarantee that the "backfill" in the drain trenches will be permeable enough to allow vertical water movement (Fig.3).
It follows, then, that an additional sub-surface drainage system would be needed, but now at shallow depth and at short spacing (order of magnitude: 10 m spacing). This system, though shallow, will be too deep to think in terms of grassed waterways which, moreover, cannot be crossed if they are wet too frequently and for too long periods. The latter is indeed expected to occur.
Open ditches at such short spacings will not be practical for various reasons. Tube drains with well permeable "backfill" in the trenches would work fine, but will be extremely expensive.

One may wonder whether the "interflow" to shallow drains, after swelling, will be sufficiently rapid to have the effects desired. Since this is likely to vary from one place or area to another, there are not sufficient grounds now for a general recommendation about a refined and costly system of shallow sub-surface drains. More detailed studies of the occurrence of perched watertables, duration of occurrence, specific soil-air régimes under perched conditions and the reaction of various crops will be needed first.

The levels attained by perched watertables and the duration of occurrence will also be strongly influenced by irrigation practices and by evaporation following water application. Well prepared land, selection of adequate methods of application, field slopes, length of runs, stream sizes and volumes of application will reduce the occurrence of second watertables. Besides, strong evaporation combined with low values of effective porosity, will cause a fairly rapid lowering of the watertable.

In conclusion: it will be worthwhile to concentrate on the possibilities of adjusting irrigation methods and practices to the specific needs of swelling clays, as a method of avoiding high perched watertables and - thus - of avoiding shallow sub-surface drains.
The effect of shallow drains on the yields of various crops should be studied on experimental fields as well.

Surface drainage system

In the absence of shallow drains, much attention should be paid to the evacuation of excess surface water resulting from irrigation. Surface drainage systems are closely linked to irrigation methods; there is no need to discuss them here.

IV. Suggested program of investigation

The following program contains only studies which are directly related to the planning of water management systems, notably of drainage systems. The program is certainly not a complete one, but may serve to draw attention to aspects of interest and provide some practical guide lines to start with. Actually, any program will have to be adapted as results of studies become available. The suggested program consists of two parts:

- investigations directed to grouping the soils of the delta in hydro-pedological units.
- investigations in view of obtaining a better insight in the specific problems of water management posed by swelling clays.

IV.1. Survey of hydro-pedological units

Guide lines for the classification into such units can, in fact, be established only when results of present soil surveys and of experiments on the IRAT-plots become available. It is possible, however, to indicate roughly the criteria to be handled.

They relate to the following soil characteristics:

a) the capacity of soil layers of sufficient thickness to absorp irrigation water at a rate which satisfies crop requirements.

b) the possibility of water to seep through the rootzone into the subsoil. On an annual basis, for salt balance reasons, it must be reckoned that a volume of about 200 mm (maximum) must percolate out of the rootzone. If this volume is divided by the number of irrigations an order of magnitude is obtained about criteria to be applied.

c) the transmissivity of subsoil and deeper strata. As a guide line: a value of less than 1 m^2/day would lead to narrowly spaced, costly drains; a value of 3-5 m^2/day may be considered favourable (spacings in the order of 100 m). It goes without saying that the depth of the drains, the required rate of drainage and, particularly, the cash value of the crop are of great influence on such criteria.

d) salinity and alkalinity. Soils which need substantial leaching prior to cropping should be considered unfavourable, unless drainage conditions are excellent.

e) specific phenomena of swelling clays, such as extent of swelling, soil moisture retention, air content under conditions of waterlogging.

Furthermore, the following practical observations may be made:

- the density of observations can best be judged by the pedologist; it depends largely on the degree of homogeneity of soils present.

- the permeability of the soil below the 50 cm level will be largely determining the spacing of the deep drains.
  The recommended method of measurement is the"Augerhole Method",which applies to soil below the phreatic level. Laboratory methods are not suitable for calculations of drainage systems. The results of methods to determine permeability in unsaturated zones carry the risk of being hard to evaluate under saturated conditions.

- since the "augerhole method" 1) will normally yield data of soil layer below the 0.5-1.0 m level (i.e. 1 m below ground surface), there remains the problem of the presence of flow barriers in the upper stratum of the medium textured soil. Suggested methods of examination are:

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1) The method is described by W,F.J. van Beers in "The augerhole method", Bulletin 1 of the International Institute for Land Reclamation and Improvement, Wageningen, Netherlands (copy present at F.A.O.office, St.Louis).

. determining infiltration rates with infiltrometers after having removed the clay cover. The cylinders may be placed at various depths. Measuring infiltration rates in the fissured upper clay layer is not expected to yield reliable results.

. applying "potential sondes" - very tiny piezometers to be obtained from "Grontmy Ltd, Houdringhe, DE BILT, HOLLAND" - just above and below thin layers which are thought to present flow barriers. This can be done only in bigger fields to which water is applied (IRAT plots, cuvettes temporary flooded in the wet season) since the possibility of horizontal flow over tiny barriers toward adjacent non-wetted areas is too great on small plots.

- regular examination of the soil profile till a depth of 4-5 m, primarily to find the location of an impervious floor, will indispensable. The larger the thickness of the aquifer, the wider the drain spacings. It would be best to include such depths in the present programme of soil surveys.
- A few pumping tests at shallow depth will be highly useful for the determination of the transmissivity of the soil layers below the root-zone. If the soil is stable enough, the holes for pumping and piezometers can be made with a hand auger. A small pump, having a capacity of a few litres per second, will do.

IV.2. Investigations into some specific watermanagement aspects of swelling clays

This type of investigation relates to the hydrological behaviour of swelling clays of varying thickness as influenced by both physical and chemical properties. Since soil tillage operations, crops to be grown, irrigation methods etc., will all have a considerable impact on the physical behaviour of the claysoil, the studies should be undertaken in close cooperation with agronomists and irrigation engineers. The following investigations will be largely conducted on experimental fields. Research in the laboratory is to accompany work on the fields.

a. IRAT-experiments

- Continuation of measurement of watertable fluctuations and drain discharges.

From the watertable hydrograph or the hydrograph of outflow, the permeability, the transmissivity and the effective porosity may be obtained through application of transient flow equations [1].

It is suggested to limit - for the time being - the observations to a few sample areas, which are indicated below (plots with additional piezometers). By doing so, the reliability of the observations will be improved and the chances are that a better insight is obtained in the processus of water infiltration and drainage.
It is strongly recommended to process and evaluate the results directly after completing a series of observations which is thought to refer to the period between two successive irrigations (2-3 weeks). Phenomena which are not understood may become clear through adjustments in the programme during the following series.

- Piezometer observations

It is suggested to install a few additional piezometers in sample areas having their filters at about 1.50 m depth.

a) a new line of piezometers midway between the two existing lines on plot CD.

viz.: 1 piez. on top of drain D
" at 0.5 m from drain D
" " 1.0 m " "
" " 2.0 m " "
" " 4.0 m " "
" " 25.0 m " "
1 piez. on top of drain C
1 piez. at 0.5 m from drain C
1 piez. at 2.0 m " " "

b) two piezometers on plot DE at the same distance from drain DS 6 as sub a) : 1 piez. midway between D and E
1 piez. at 1 m from D.

1) D.A.Kraijenhoff van de Leur: A study of non-steady groundwater flow, with special reference to a reservoir coefficient. Part I, de Ingenieur 70: B 87-94-1958, Part II, de Ingenieur B 285-292, 1962.

c) two piezometers on plot BC, as
sub b) : 1 piez. midway between B and C
1 piez. at 1 m from C.

d) same as sub a), b) and c), but now on plots IJ, JK and HI respectively.

Note: . in view of the soil stratification it will be particularly important to install piezometers in such a way that no downward movement of water takes place along the pipe. To that end it is recommended to place the piezometer pipe in a wider handmade augerhole and fill up the space between pipe and wall of the hole with wetted clay, which, then, is compacted. The filter should first be surrounded by well-permeable materia, such as coarse sand (without mica).

. observation frequency as is currently being effected: normally daily, a few more observations during irrigations and on the day following irrigation. The frequency may be reduced once the water table behaviour becommes better known.

. shallow piezometers - depth 40-50 cm - to be added to the scheme, with a view to tracing the occurrence of perched watertables. Use, for this purpose, also the "potential sondes", which are to be installed at several depths in the upper 1 meter of soil.

. the functioning of existing piezometers should be checked.

- Discharge observations

. daily observations of discharge of drains C, D, I and J. During irrigation and on the day following irrigation, more frequently (every 2 to 6 hours depending on the rate of watertable reaction).

. check the functioning of drains not mentioned above, place piezometers on top of drain tubes. The permeability of the backfill in the drain trenches may be checked by shallow piezometers or open augerholes, which will indicate the presence of perched watertables in the trench.

- Permeability measurements

Use augerhole method. Make use of temporary high watertables to measure higher soil layers. Describe soil texture and structure during augering as accurately as possible.

- Soil salinity and moisture

  To provide better means of evaluation of experimental results, measure soil salinity and moisture content before, during and after irrigation on the sample plots (neutron or otherwise).

- Irrigation methods

  Irrigation of industrial crops on swelling clays requires special techniques if perched watertables are to be prevented or minimized. Therefore, measure accurately volumes of water applied, introduce variations in irrigation frequencies, install "potential sondes" to observe perched watertables etc. Readings of infiltration rates preferably every 5 minutes during the first half hour of the measurement.

- Additional sample areas

  If there are distinctly different soil profiles on the 120 HA IRAT plot, then an additional experiment as on plots CD or IJ should be carried out on the other profiles as well.

b. SAED-plots

. increase of piezometer readings on tomato- and bean plots till daily observation.

. measurement of permeability and studies of irrigation systems, see IRAT-experiments sub a.

c. Additional observations

- examination of behaviour of swelling clays during cultivation: measurement of infiltration rate, bulk density etc. Is the rapid reduction of infiltration rate due to swelling, to soil structure deterioration which may follow leaching of soluble salts, or to a combination of both of them? What influence is it going to have on irrigation practices?
- studies of salinity criteria - both soluble salts and adsorbed sodium . Since it may be desirable to let the soil dry out further than is commonly practised in irrigated agriculture, elsewhere accepted criteria may have to be adapted. The same applies to criteria concerning the quality of irrigation water. It will be worthwhile to examine also the methods of analysing swelling clays for adsorbed sodium.

- studies of desalinization methods, such as continuous ponding, intermittent leaching, leaching by sprinkling. Leaching with sea-water - or diluted seawater - does not seem practicable. The watertransmitting properties of the soils are probably such that one risks to apply salts to the soil which cannot easily be removed.