IICA - Interamerican Institute for Cooperation on Agriculture

Short term consultant's final report

by

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Petrolina PE - Brasil

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Petrolina/Recife, August 1982

1 OBJECTIVE AND GENERAL APPROACH

The objective of the consultant's mission, as specified in the job description attached to his appointment letter ref. ZS/BBEC-1422 dated June 1st, 1982, was: to advise the CPATSA to improve its research in drainage and salinity.
After consultation with Dr Antonio José Simoës, acting-head, and Dr Edson Lustoza de Possídio, technical director of CPATSA, considerable time was devoted to review the reports and also a large amount of as yet unreported data of concluded investigations by CPATSA, as well as to get acquainted with the projects and present stage of progress of the ongoing investigations. The investigations on salinity already concluded by CPATSA were mostly done in the São Gonçalo irrigation scheme in the state of Paraiba (Gilberto Gomes Cordeiro, research officer). Presently underway by CPATSA are a survey of the phreatic waterlevel fluctuation at the Bebedouro experiment station (Paulo Cesar Farias Gomes, research officer) and an experiment on irrigation of fodder grasses with rather saline well water of EC = 2,6 mmhos/cm in the dryland area at CPATSA (José Monteiro Soares, research officer). Actually most of the ongoing investigations are phreatic waterlevel and soil salinity surveys, which are carried out under the coördination of CPATSA by the state enterprises for agricultural research in several DNOCS irrigation schemes, under an agreement between SUDENE/DNOCS/EMBRAPA. For a better appreciation of the problems, visits were made to these irrigation schemes.

2 IRRIGATION SCHEMES AND INSTITUTIONS VISITED

(for detailed itinerary see appendix 1)

a) *Perimetro irrigado Vaza-Barris (PIVB)*, State of Bahia, near town of Cocorobõ. Dam completed in 1966, irrigation scheme still being developed. Present facilities can irrigate 912 ha, but actually only about 500 ha are in production, with 102 farmers (colonos). The remaining 420 ha were originally put under irrigation, but had to be abandoned and the farmers relocated in other lots, for reasons of severe salinization of the heavy soils. The affected area is awaiting reclamation. A study for the installation of sub-surface (tile) drainage has been made by the IRYDA (Spain) mission in DNOCS, and a small stock of drainpipes is available on the project. Installation of the tile-drains is waiting for the drainage machine, recently acquired by DNOCS, and presently located in the Morada Nova scheme (see 1) below). The irrigated area is located in the rather narrow alluvial valley of the Rio Vaza-Barris, immediately downstream of the dam. The valley shows the typical pattern of river deposits: levee soils of light to medium texture and a topographically high position along the river, and basin deposits of heavy clay soils and a relatively low topographical position further away from the river. As the river has changed its course through the valley during the years, a very complex soils pattern has developed. Soil surveys have been made, but the maps and reports were not available in the project office, neither was the report of the drainage study. Because of the relatively low elevation of the irrigated area above the river draining the area, high phreatic waterlevels will soon develop after irrigation is started.

If the groundwater or the subsoil contains soluble salts, these may move up in the profile with the water and accumulate in the rootzone layer. This is likely to occur especially in the lower lying soils of heavy texture and low hydraulic conductivity (permeability for drainage and percolation water), as has been experienced.
In the area under irrigation a soil salinity survey and a survey of the phreatic waterlevel is being carried out by EPABA. Soil samples have been collected in a rigid 100 x 100 m grid, but their analysis is delayed due to lack of capacity in the DNOCS soils laboratory. Observation wells have been installed on a 300 x 300 m grid, and readings have already been collected for several months. This investigation appears to be well underway. The grid pattern has been very strictly applied, without bearing any relation to the infrastructure and parcellation of the area. This complicates the easy use of the date by the project management.
To discuss the progress of the soil salinity and phreatic water survey a meeting was held in the DNOCS project office, with the following officers participating:
Eng°. Sandoval Gonçalves Felix, chief Irrigation Division DNOCS/ 4°D.R.
Eng°. Acarcio de Jesus, manager PIVB - DNOCS.
Eng°. Rosael Carvalho do Vale, research officer EPABA, in charge of the surveys under reference.
Eng°. Gilberto Gomes Cordeiro, CPATSA, and consultant.

b) *Perimetro irrigado São Gonçalo (PISG)*, state of Paraiba, near town of Souza. Oldest irrigation scheme of DNOCS. Dam completed 1934, irrigation started ± 1940. Irrigation scheme was rehabilitated and reorganized as a colonization scheme around the 70's. Gross area of scheme 3900 ha with a nett irrigable area of 1900 ha. Only 1300 ha are in production by 329 colonos, the remaining 600 ha are out of use due to severe salinization of the soil. CPATSA has made a detailed survey of soil salinity in the area actually under irrigation, and attempted some reclamation experiments in severely salinity affected sites (Eng. Gilberto Gomes Cordeiro).

Also, in 1976/1977, some drainage tests were made on pipedrains installed before 1960 by hand-labour in wide machine-excavated trenches (Eng. Paulo Cesar Farias Gomes). The detailed salinity survey is presently being extended by EMEPA to the 600 ha not under irrigation. Also the reports of a detailed soil survey and rehabilitation study, carried out for DNOCS in 1968/1972 by a consulting firm, could be gone through. A survey of the phreatic waterlevel in the irrigated area is to be carried out by EMEPA, but this study has not yet started, nor has the observation network been designed.
As a general conclusion from the available data it may be stated that the salinity problem, for which this irrigation scheme is widely known, is mostly *a problem of non-saline, sodic soils* with high to very high ESP-values of up to 50 or 80% (exchangeable sodium percentage, adsorbed on the clay particles).
These soils often show a very dense structure, high bulk density and very low permeability for water. These factors make it practically very difficult to reclaim these soils, as it will be hardly possible to obtain sufficient leaching and drainage in these soils. Reclamation experiments in small plots of 16 m^2, have shown that with gypsum application of 15 to 40 tons/ha rice yields of 4 to 6 tons/ha are possible. However no lowering of the ESP-value of the soils could be shown, apparently as hardly any leaching could be effected.

c) *Perimetro irrigado Engº Arcoverde, at Condado, State of Paraiba.*
Small irrigation scheme started in 1972, supplied from a dam constructed in 1936. Irrigable area 281 ha, of which only 156 ha are under irrigation by 40 colonos. The remaining 13 lots are not being operated for reason of salinization of their soils. At the time of the visit, it was foreseen that the irrigation supply would have to be stopped in one month time for lack of water in the dam. Large wells had been excavated to pump phreatic water in an attempt to save the banana plantations. A soil salinity and phreatic waterlevel survey is being done by the CCT - Centro de Ciências y Tecnologia of the Universidade Federal da Paraiba at Campina Grande.

d) *Perimetro irrigado Sumé,* Paraiba. Dam constructed 1960/61; irrigation scheme started in 1970, approx. 255 ha irrigable area. 46 Lots of 3 to 7 ha net irrigated area are in production, whereas 5 lots have not been utilized as yet for reason of saline soil or ownership problems. The irrigated area lies in a narrow strip along a relatively deep cut-in river bed, which makes for a rather favourable natural drainage situation. According to the scheme manager Eng. José Fernandez, who is already in the project for 15 years, no salinity problems have developed since the start of irrigation. The scheme seems a well-run, successful project. A soil salinity and phreatic waterlevel survey is being made by the CCT - Universidade Federal da Paraiba.

e) *Universidade Federal da Paraiba:* CCT - Centro de Ciências y Tecnologia, Dep. de Engenharia Agrícola, Campina Grande.
Discussion about progress and presentation of data on maps of phreatic waterlevel and soil salinity surveys in irrigation schemes Condado and Sumé.

f) *IPA - Empresa Pernambucana de Pesquisa Agropecuaria,* Recife. Discussion on progress and presentation of data on maps of soil salinity and phreatic waterlevel surveys carried out by IPA in Moxoto irrigation scheme (Eng.º Milchiades Montenegro Filho, Eng.º Maria José Coelho Soares).

g) *EMBRAPA - Servicio Nacional de Levantamento de Solos,* Recife. Discussion with Dr Luiz Bezerra Oliveira on the planning and execution of phreatic waterlevel surveys, especially with regard to the study undertaken by IPA in Moxotõ irrigation scheme.

h) *Perimetro irrigado Moxotó,* near Ibimirrim, state of Pernambuco. Dam completed in 1957, irrigation started in 1977. Presently about 1800 ha under irrigation, with 221 colonos. The irrigated area, occupying a width of about 2 km on both sides of the Rio Moxotõ, has rather irregular topography. On the levee soils no problems are apparent, but in the basin areas drainage problems are obvious.

The existing open main drains are heavily choked with aquatic vegetation, and very high waterlevels were present, which could well be recharging the groundwater rather than draining. It might well be possible that automatic overflows from the irrigation canals during nighttime are an important contributing factor to this undesirable situation. Reportedly a flow of 4300 l/sec is fed into the canal system for day-time irrigation, but during nights a flow of 1000 l/sec is maintained to keep the canals, controlled by automatic gates, filled with water. Presumably a good part of this night-flow escapes directly to the drains at various points in the lower parts of the area. A soil salinity survey and phreatic waterlevel study are being carried out by IPA. Some 112 observation wells have been installed, the first ones already 5 months ago. Regular waterlevel readings, however, have as yet not been taken.

i) *IPA - Serra Talhada.* Discussion on phreatic waterlevel survey in Moxotó irrigation scheme with Eng^{o} Antonio Raimundo de Souza.

j) *DNOCS - Administração Central,* Fortaleza. Discussions on drainage problems in DNOCS irrigation projects with Director of Irrigation (Eng^{o} Francisco Franco de Abreu Pereira) and co-workers (Eng^{o} José Hugo and Eng^{o} Antonio Pontes de Aguiar Junior) and members of IRYDA mission (Eng^{os} Antonio Alonso de la Câmara and José Luis Pérez Abelairas). The design report 'Projeto de Recuperação dos Solos do Setor I do Perimetro Irrigado Aires de Souza, Sobral CE' prepared by DNOCS/IRYDA was borrowed as an example of the investigation and planning method used for the design of sub-surface drainage.

k) *Perimetro irrigado Curú - Paraipaba, Fazenda experimental de la Universidade Federal do Ceará,* Centro de Ciências Agrárias, near town of Pentecostes. Discussion with Dr José Matias Filho on drainage and reclamation of salinity affected soils in irrigation projects.

l) *Perimetro irrigado Morada Nova,* state of Ceará. This irrigation scheme started operating in 1970/1971. It has 3600 irrigable area, of which 2600 ha are actually in production with 480 colonos. Water is taken from a diversion weir in the Rio Banabuiu near the town of Morada Nova, which is supplied from a reservoir dam 60 km upstream. The irrigated area stretches for a distance of 30 km along the river, on the alluvial soils of the valley.

The river bed is rather shallow, so that effective drainage, especially of the lower lying basin areas, is hampered by the small slope available in the open main drains. Subsurface drainage (high groundwater level) and sodic soil problems are apparent. For this project DNOCS has acquired, since a few months, a drain-laying machine for installing tile-drains and a drain-cleaning machine for cleaning out pipe drains with a jet of water under high pressure. Both machines were shown, and the drain-laying machine demonstrated.

As yet about 20 ha of tile drainage, in sodic soil, has been installed with the drainage machine. Unfortunately the work had to be interrupted for lack of funds. Another 30 ha had been tile-drained previously, laying the pipes by hand in a wide trench excavated with a hydraulic back-hoe excavator. Undoubtedly the procurement of the drainage-machine is a great step forward.

Tile lines were installed at 12 m spacing and 1,4 m depth at the outflow end (about 1,2 m average depth). Ceramic (clay) pipes were used, of 7,5 cm internal diameter x 10 cm square outer section x 31,5 cm length. The somewhat unusual square form of the clay pipes has obvious advantages in the fabrication process, when they are made in a factory equipped for manufacturing hollow bricks, as only minor modifications in the production line are required. For the installation or the functioning of the drains, there will be hardly any difference with round (cilindrical) pipes. The pipes were of reasonably good quality. The only weak point was that the ends of the pipes, which need to butt together closely, were not always perfectly free of burrs and not always cut perfectly perpendicular to the length axis. As a result rather open joints, up to 1 cm, occured in the tile line. No cover material of any kind was used on the pipes, the trench being refilled with the excavated (sodic) soil. Reportedly the use of a cover material on the pipes was not considered necessary or economically justified, as a cleaning machine is available to flush out the pipes in case they should get choked. This however, in the consultant's opinion, is a very doubtful consideration. The need to cover the drain-pipes with a fine gravel, yes or no, should be thoroughly investigated. Also the application of gypsum to the excavated soil used for refilling the draintrench would seem very desirable when the drains are installed in sodic soil, or with a sodic soil layer in the profile.

3 EVALUATION OF DRAINAGE AND SALINITY PROBLEMS AND RELATED RESEARCH ACTIVITIES

In general it may be stated that the DNOCS irrigation schemes are located on alluvial deposits in small river valleys. They show rather irregular topography, and considerable variation in soil conditions. The light to medium textured levee-soils generally are found in the relatively higher parts, they mostly have higher permeability for water, and as a consequence are usually in a somewhat more favourable situation for natural underground drainage. The more heavy textured basin soils occupy the lower lying parts, have lower permeability for water and are often situated further away from the main river channel. As a consequence these parts are usually in a rather unfavourable situation for any natural underground drainage. When irrigated they soon develop a phreatic watertable at a shallow depth below groundlevel, of the order of 1 to 1,5 m, only maintained at that shallow depth by the processes of capillary rise and evapotranspiration, the natural underground drainage often being negligible. Hence, considerable difference may be expected within the same irrigation scheme with respect to depth of groundwaterlevel below the land surface and natural underground drainage, both important factors for salinity control in the rootzone layer.
The salts contained in the irrigation water are always an important source of salinization of the soil, even if the water is of good quality. The salinity of irrigation waters used in the DNOCS schemes varies in the range of 0,3 - 1 mmhos/cm EC, considered of good to reasonably good quality. To prevent the accumulation of salts to intolerable levels in the rootzone layer a certain amount of leaching is always required.

That is to say, a percentage of the irrigation water applied must percolate through the rootzone layer, removing the excess of salts out of the rootzone layer. The amount of leaching required in relation to the salinity of the irrigation water and the salinity level tolerated in the soil in accordance with the crops to be grown, can be estimated from a water balance and corresponding salt balance for the rootzone layer. An elaborate discussion of this subject can be found in ILRI Publ. 16, Vol. 2, Ch. 9 and FAO Irrigation and Drainage Paper 29, references (1) and (2) given at the end of this report.
The leaching water percolating down below the rootzone joins the phreatic groundwater. As a result the groundwater level tends to rise. If the groundwater gradient and subsoil permeability are large enough, the natural drainage to the river or other natural drainage channel may be sufficient to drain off the percolation water. Such a favourable situation may exist in some parts of the irrigation schemes. In large parts however the natural underground drainage is insufficient to drain away the leaching water, or is even negligible. Then the groundwater level rises to within a shallow depth below the land level, 2 m or less. Then through capillary action in the unsaturated soil pores, water may rise up to within the rootzone and be lost by evapotranspiration. How much water will rise up by capillary action depends on the suction gradient between the groundwater level and the rootzone, on the type of soil (capillary conductivity) and on the height above the groundwater level.
With the ascending water, salts move up into the rootzone. Under these conditions leaching cannot be effective, as the leaching water is not drained away, but instead returns to the rootzone. The capillary rise of water from a shallow groundwater table is another source of salinization of the soil, especially when the groundwater or the subsoil has a high salt concentration. It is often the most important cause of salt accumulation in the soil. This situation is likely to occur in large parts of the irrigation schemes.

To remedy such an unfavourable situation it is necessary to provide sufficient subsurface drainage in order to lower the prevailing groundwater level so as to reduce the capillary rise of water to the rootzone layer and to drain away the leaching water.

It may be foreseen that for these reasons large parts of the DNOCS irrigation schemes in NE Brazil will eventually have to be provided with purposely installed subsurface drainage systems to achieve and maintain an adequate degree of salinity control.

The design of a suitable subsurface drainage system, with respect to depth and spacing of drains is normally based on known drainage theories, applying established criteria and data derived from purposely undertaken soil-hydrological investigations (hydraulic conductivity, depth to impermeable layer), where possible combined with the analysis of results of similar drainage systems already constructed in the region. As the drainage theories always are a simplified model of the real situation, and the soil-hydrological investigations yield a large range of data from which it is difficult to decide on a representative value for the design (hydraulic conductivity e.g.), it is always very desirable to compare with experiences under similar situations. Also the criteria to be applied, might need to be verified, if drainage is to be undertaken in a new area. A valuable discussion of drainage design factors can be found in FAO Irrigation and Drainage Paper 38 (ref. 3). Also in new areas the construction method of the drain, using locally obtainable materials, often needs to be tested in the field in order to make sure that functional drains are installed in which the water can enter easily without too high entrance resistance and that will remain in functional condition for a long period. In the consultant's opinion this aspect needs high priority in NE-Brazil. Especially the need to use fine gravel as a cover material on the drainpipes to bridge the large open joints between the clay ware drainpipes and to provide a region of high permeability along the drainline, should be urgently investigated in field drainage tests. Also the application of gypsum to the excavated soil when refilling the drain trench should be included in the tests, when drains are to be installed in sodic soils.

The drainspacing of 12 m as presently used in the Morada Nova irrigation scheme would seem rather narrow, and it may well be questioned whether such a narrow spacing is economically justified. Drain spacings in irrigation areas are normally in the range of 25 to 50 m. The narrow drain spacing may have resulted from a large margin of safety included in the design and very severe drainage criteria applied.

The expert consultation on drainage design factors, convened by FAO in 1979, considered that 'designing drainage systems on the basis of allowable duration of water in the rootzone, is not sufficiently defined at present to make general recommendations' (ref. 3, pag. 22). In the consultant's opinion also the drain spacing needed, in relation to drain discharge and groundwatertable fluctuation, should be investigated in field drainage tests, as obviously the drain spacing has a large bearing on the cost of a drainage project.

Until recently much emphasis has been given to determination of the salinity status of soils in the irrigation projects. From the large quantity of analysis data it has become clear that the major problem encountered is that of non-saline sodic soils, showing high and sometimes extremely high exchangeable sodium percentages to a considerable depth in the soil profile (samples were mostly taken to 90 cm depth). In several schemes lots had to be abandoned and the colonos relocated in other lots for reasons of 'salinization'. In fact, it often concerns sodic soils that soon after irrigation was started, were found to be infertile and very difficult to be cultivated, due to a series of problems related to the poor and unstable structure as a result of the dispersion of the clay particles (poor workability, low infiltration rate, dense structure, hard surface crust etc.). It may well be questioned whether such problematic, highly sodic soils should at all be considered for irrigation.

Some small scale reclamation experiments have been attempted, applying gypsum and 'leaching'. So far not with very encouraging results. It seems that the worst affected sites were selected for these experiments (heavy soil texture, very high ESP to considerable depth, no effective subsurface drainage). Though water was applied for leaching, in fact hardly any leaching will have occured due to very low soil permeability, combined with a groundwater table at shallow depth and no effective underground drainage.

Phreatic waterlevel surveys have recently been initiated. These studies are very useful to get an insight in the development of groundwater tables in the irrigated areas. They are however laborious.

In general these studies seem to be well set up. The following remarks may be made:

- Waterlevel readings in the observation wells should be made at least once a month, and be continued for a minimum period of $1\frac{1}{2}$ years, so as to cover a full annual fluctuation cycle.
- At the same time data on irrigation, rainfall and waterlevel in open channels should be noted.
- The investigator should plot the observations on hydrographs (plot of waterlevel against time) as soon as possible after readings have been taken. In so doing, doubtful and may-be erroneous readings are spotted and can be repeated or the cause verified, and the necessary measures taken before the next reading date (e.g. cleaning, repair or replacement of well).
- Observations should be started as soon as wells have been installed, even if the whole network is not yet complete.
- Two or three times per year water samples should be taken from the wells and analyzed for EC and dissolved cations and anions (Ca, Mg, Na, K, Cl, SO_4, HCO_3, CO_3).

4 RECOMMENDED PROGRAM OF RESEARCH ON DRAINAGE AND SALINITY CONTROL

In order to provide a sound basis for the rational design of sub-surface drainage systems, research is recommended along three main lines. These are in order of priority:

1) field drainage experiments
2) phreatic water level surveys
3) surveys for soil salinity.

In addition reclamation trials on sodic soils could be made in carefully selected pilot areas, in combination with a field drainage experiment.

4.1 Field drainage experiments

It may be foreseen that sub-surface pipe drainage systems will have to be installed eventually in large parts of the DNOCS irrigation schemes to avoid a decline in productivity due to excessive wetness of the soils and accumulation of salts caused by too high groundwater tables. The recent procurement of a drainage-machine by DNOCS will greatly facilitate the installation of pipe drains. However, experience as to the most suitable construction of agricultural pipe drains (materials to be used and way of installation) and as to the design of pipe drainage systems (depth and spacing) does - practically speaking - not exist. Neither is it known if design criteria used elsewhere, are applicable for the conditions prevailing in N.E. Brasil (design discharge rate and corresponding average or fluctuating watertable elevation). Moreover, soil properties often show great variation at short distances even within the same soil type.

Due to this variation in properties, drainage designs based on soil investigations and criteria taken from elsewhere, are always subject to a degree of uncertainty and their suitability needs to be verified.

In the present stage of development it is considered of highest priority to carry out systematic investigation in the form of practical field drainage experiments in order to get answers to the questions raised, determine the best combination of drainage materials, verify the suitability of designs and design criteria, and generate the necessary experience.

Preferably field drainage experiments should be laid down in several irrigation schemes, before drainage systems on a larger scale are installed.

A good description of the methodology used for these drainage test fields is given in FAO Irrigation and Drainage Paper 28 (ref. 4), the reader is referred to this publication for technical details of how to conduct such tests.

Each test field should have 5 pipedrains, of which 3 are to be measured and 2 are 'buffer' drains to assure symmetric conditions (See Figure).

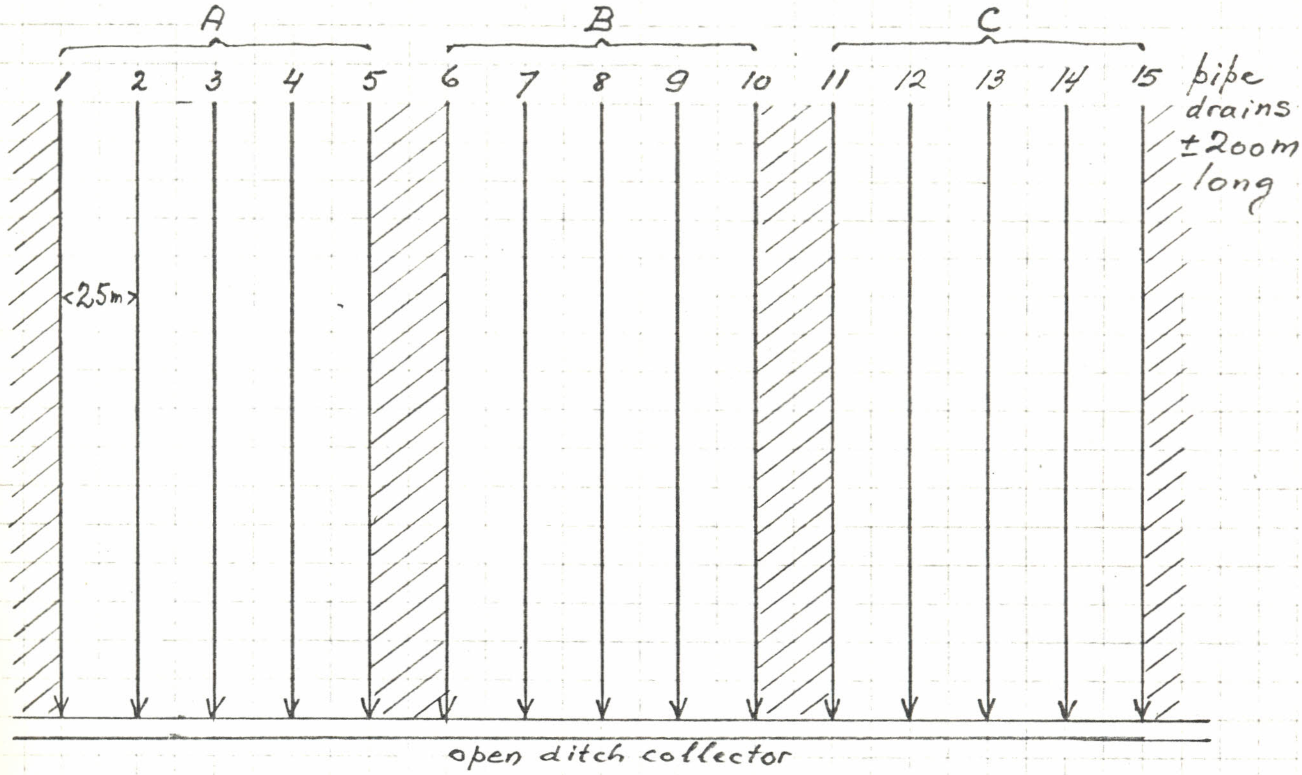
The length of drains should be 5-10 times the spacing, in order to reduce the border effects of a deep collector ditch at the outflow end and of inflow from an undrained adjacent field at the upstream end.

Starting from a drain spacing of 25 m, the drainlength should be around 200 m, so that one test field will occupy about 5 x 25 x 200 m^2 = 2,5 ha.

Because of this size the number of treatments to be investigated, must necessarily be limited to those which are expected to be of immediate practical applicability if found suitable. For the same reason replicates are usually not possible, so that a statistical evaluation of results, as is customary in agronomic (e.g. fertilizer) experiments, cannot be made.

Instead results are evaluated measuring drain discharges and ground watertable heights in piezometers placed in the middle between two drains and at a short distance beside the drains, during a period of time.

Figure a): Schematical lay-out for field drainage experiment with 3 drain types ('treatments')



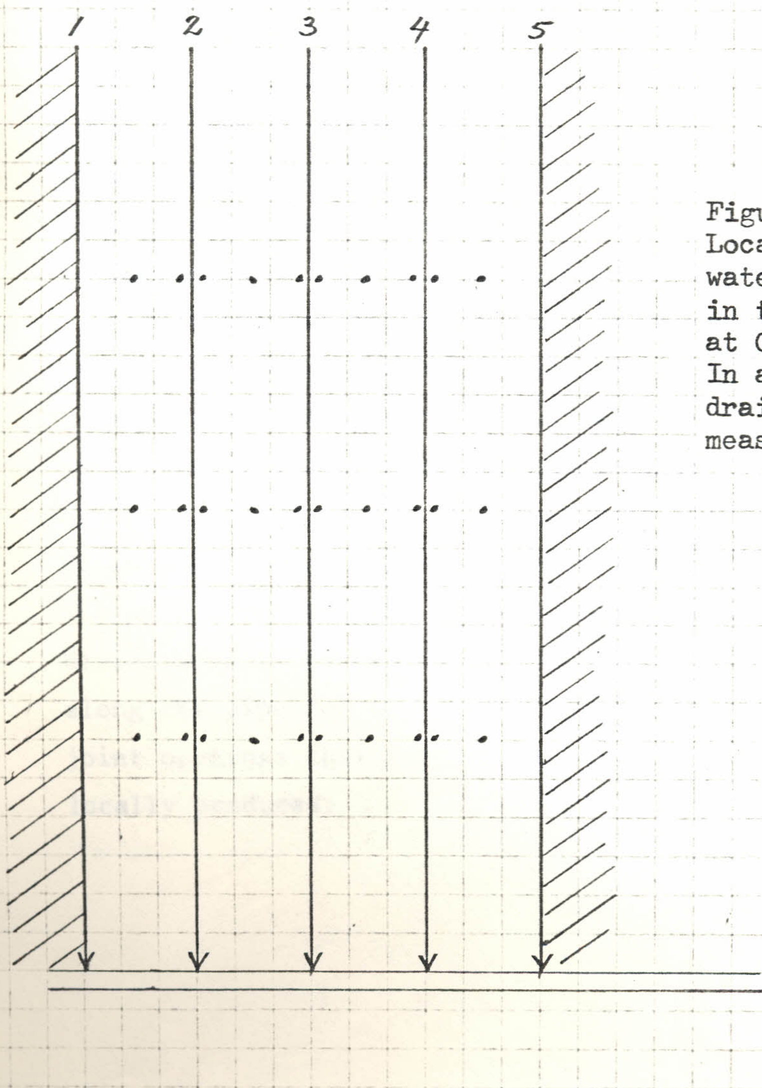


Figure b):
Location of piezometers for waterlevel observations in 3 rows, in the middle between drains and at 0,4 m beside the drains.
In addition the discharge from drains 2, 3 and 4 is to be measured.

From the so obtained relation of discharge vs. watertable height the effectiveness of the drain construction in terms of the entrance resistance for water can be derived, as well as the total hydraulic head required for a specific drain discharge. From these data the transmissivity (hydraulic conductivity x thickness) of the layer through which the drainflow takes place can be derived, as a check on the data obtained from auger hole determinations. The relation can also be extrapolated for larger drain spacings.

Care must be taken that the whole trial field be irrigated in the shortest possible time, so as to have as much as possible the same recharge condition over the whole field. Also for this reason too large trial fields, with very wide spacings, should be avoided. Often in one irrigation season, taking the necessary observations during a number of drainage events after irrigations, sufficient data can be collected to allow important conclusions with regard to the effectiveness of the drain construction and of the drainsystem. Also data are obtained on the drain discharge resulting from the irrigation practices used.

To start with, drainage test fields should be laid out to determine the proper drain construction, using locally obtainable materials. Especially the question if gravel is required as a cover material on the clay pipes or can be dispensed with, should be answered. The following treatments are proposed:

A: clay pipes only - no gravel - trench refilled with excavated soil

B: clay pipes - fine gravel applied in trench to 8 cm above the pipe - trench further filled up with excavated soil

C: if soil profile contains sodic layer: As B, but with gypsum mixed with the soil used for refilling the trench.

In a further stage, when the question as to the proper drain construction has been solved, field drainage tests with 2 different spacings and drain depths (e.g. 1,4 m/25 m and 1,8 m/50 m) may be made.

The purpose of the gravel as a covermaterial on the pipes, when the drains are placed in clayey soil, is to provide a good permeable area along the pipe for easy waterflow to the joints and to bridge the large joint openings that are practically unavoidable with the clay pipes as locally produced.

The gravel should be a graded material with particle sizes ranging mainly between 2 and 25 mm, with less than 5% by weight of particles smaller than 0,4 mm and no stones larger than 38 mm. It is suggested that a locally available, naturally graded material is sought, which can satisfy this size range with little or no treatment as breaking or sieving.
When the drains are placed in sandy soil, the grading of the gravel must be adapted in accordance with the soil material. In that case it is recommended to apply the specifications developed by the USBR.

4.2 Phreatic water level surveys (groundwater surveys)

As waterlogging problems and salinity problems are related to a groundwater table at a shallow depth below the groundsurface, it is important to have a good insight in the prevailing groundwater table fluctuations in any irrigated area. In particular the aim of these surveys is to delineate the areas where shallow groundwatertables occur (location, extent and degree) and to find the direction of groundwaterflow, so as to evaluate where natural drainage occurs, and where it is deficient and additional (artificial) drainage needs to be provided.
The network of shallow observation wells with a density of roughly 1 point per 25 ha, should cover the whole irrigation area and should be designed after a thorough study of all relevant data on the project area, such as topographical maps, airphotos, projectmaps showing contour-lines of the land surface, soil survey maps, hydrologic data etc. All this information will have been produced in the past for the design of the irrigation project, and should be located, collected, borrowed and copied, in order to be studied in the office. Hardly anything of this kind is available at CPATSA. Every new study to be undertaken, should start with a preliminary phase in which this material is collected at CPATSA and studied.
The observation network need not necessarily follow a strict grid pattern, but should be so designed that a good groundwatertable contour map can be drawn from the observations.

To this end observation wells should be placed along and perpendicular to lines of expected groundwaterflow, at locations where changes in the slope of the watertable may be expected, and along lines perpendicular to streams or natural drainage channels, as much as possible in readily accessible sites. (Where the study has to be entrusted to inexperienced staff, a strict grid pattern may be more practical to start with).
The location of the observation wells should be marked on a project map, showing the existing infrastructure as irrigation canals, roads, lot boundaries etc. For each observation well a location sketch should be made, so that the well can always be located also by other personnel not involved in its installation.
Monthly readings should be taken for a minimum period of $1\frac{1}{2}$ years, so as to cover a full annual fluctuation cycle. These readings converted to depth below groundsurface or to absolute elevation of the waterlevel, should be plotted on hydrographs as soon as possible after the observation date. From the hydrographs important information can be deducted: rate of rise or fall of the waterlevel; periods of the year when critically shallow watertables occur; in combination with relevant information on irrigation and rainfall they may help to understand the cause of observed watertable fluctuations; areas of similar watertable behaviour may be delineated. From the hydrographs one also decides for which month(s) to draw a depth-to-watertable map and a watertable contour map (e.g. months of shallowest watertable and month of average or lowest watertable).
Some remarks with respect to the on-going groundwater surveys were already made in chapter 3 of this report.
For a more elaborate discussion on this subject the reader is referred to ILRI Publ. 16, Vol. III, Ch. 21 (ref. 5).

4.3 Soil salinity surveys

As soil salinity is a potential danger to agricultural productivity in any irrigation scheme, it is very desirable to periodically monitor the salinity status of the soil. The methodology followed by CPATSA, systematically sampling the soil in 3 layers to 90 cm depth (0-30, 30-60 and 60-90 cm) at one sampling site per ha, is considered adequate.

In order to reduce the large amount of sampling and analysis work, attention should be concentrated on those parts of the irrigated areas where problems of salt accumulation might be expected as deduced from poor or patchy growth of crops, shallow groundwatertables, or previously measured soil salinity. A period of 5 years between surveys would appear to be adequate in most cases, unless very saline irrigationwater is used, or the phreatic water has high salinity.

The following analysis should be done on the samples:

- EC of saturated extract
- soluble cations and anions in saturated extract (Ca^{++}, Mg^{++}, Na^{+}, K^{+}; $CO_3^{=}$, HCO_3^{-}, $SO_4^{=}$ and Cl^{-})
- exchangeable cations (Ca^{++}, Mg^{++}, Na^{+}, K^{+}, H^{+} and Al^{+++}) and cation exchange capacity
- if soil is found to be sodic, also $CaCO_3$ content by effervescence with HCl.

The soil salinity data are also very helpful in the interpretation of groundwater survey results. Therefore in areas where a groundwater survey is done, it should preferably be combined with a salinity survey in the same area.

4.4 Reclamation trials on sodic soil

Though the scientific principles of sodic soil reclamation are well understood - leaching with water containing soluble Ca-ions applied in the form of gypsum - it is often very difficult or nearly impossible to carry out due to the already strongly deteriorated soil structure in non-saline sodic soils, which may be practically irreversible. In the consultant's opinion if reclamation of sodic soils is to be attempted, one should start with pilot scale experiments of a few ha, selecting first the more favourable sites (soil of medium texture, not showing too high ESP values, with reasonable hydraulic conductivity in the subsoil at drain depth). These pilot areas must be provided with a sub-surface pipe drainage system to make sure that the leaching water can be drained off. The functioning of these drains should be monitored as in a field drainage experiment.

Soils that would require more than 20 tons/ha of gypsum to reduce the ESP to 10% in the upper 0,5 m of soil, should in consultant's opinion not be considered for reclamation. Such application would replace about 3 meq. Na/100 g of soil. Higher applications would have to be spread over many years as no more than about 10 ton/ha is expected to dissolve in a year with total water application of about 1 m. Rice can be a suitable reclamation crop, where percolation rates are low. Capillary rise is prevented as long as the rice is kept irrigated, as no suction gradient will develop. And the water in the rice field will maintain the small rate of percolation that may be possible through the poorly structured soil.

5 TRAINING OF STAFF

It was noted that the chemical aspect of soil salinity, its determination in the laboratory etc is well known among research workers and irrigation staff in N.E. Brazil. However, knowledge on the relation of soil salinity with water management and especially on the role of subsurface drainage in salinity control, appears to be little known. Training in these subjects is given in the courses mentioned below, and it suggested that research officers who are to work on these aspects in the irrigation schemes of N.E. Brazil are given the opportunity to follow one of these courses:

- International Course on Land Drainage, at Wageningen, Holland. This course is organized every year from ± 20 August till ± 4 December by the IAC - International Agricultural Centre and ILRI - International Institute for Land Reclamation and Improvement. This is a 15 weeks course. It intends to provide a thorough knowledge of agricultural land drainage in humid regions as well as in semi-arid zones under irrigation. This course is held in the English language only. As it is given in the Netherlands, only drainage practices as used in the temperate humid climate of The Netherlands can be shown to participants.
- Course on drainage and salinity control at the International Irrigation Center, Utah State University, Logan, Utah, USA. This is a 6 weeks course, dealing especially with drainage in irrigated areas in (semi-) arid zones. The course is given in English as well as in Spanish.

6 OTHER ACTIVITIES

- On 9 July the consultant presented a seminar for the research staff at CPATSA on: Salinity control and leaching requirements in irrigated soils.

- A paper, entitled: Influência da Irrigação na Salinização y Sodificão dos Solos do Projeto de Irrigação de Saô Gonçalo, was prepared together with Gilberto G. Cordeiro, on the basis of data collected by the latter at CPATSA. The paper was presented by both authors at the 1st Symposio Brasileiro do Tropico Semi-Arido in Recife on 17 August.

- On 19 August the consultant gave a presentation at the symposium on: Drainage and salinity problems in regions of the semi-arid tropics, based on chapters 2 and 3 of this report.

7 ACKNOWLEDGEMENTS

The consultant wishes to express his gratitude to Dr. Antonio José Simoës, acting-head of CPATSA, for all the facilities provided during this assignment, and to all research officers of CPATSA and irrigation staff of DNOCS who provided information, guided field visits and took part in discussions.
The whole program of work was carried out in close collaboration with Gilberto Gomes Cordeiro, research officer irrigation/salinity of CPATSA, whose kind and devoted cooperation is especially gratefully acknowledged.

Petrolina/Recife, August 1982

G. Zijlstra

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ITINERARY

Sat 19 June 1982	:	Leave Amsterdam by Varig flight RG 727
Sun 20 June	:	Arrival at Rio de Janeiro; connecting flight to Brasilia
Mon 21 June	:	Call at IICA/Brazil office, Brasilia
Tue 22 June	:	Flight Brasilia - Salvador and Salvador - Petrolina. Arrival at CPATSA.
Wed 23 June	:	CPATSA office. Afternoon free (football match World championships)
Thur 24 June	:	Public holiday in NE Brasil (fiesta San Juan)
Fri 25 June	:	CPATSA office
26/27 June	:	Weekend
Mon 28 June	:	CPATSA office
Tue 29 June	:	CPATSA office. Afternoon free (football match)
Wed 30 June	:	CPATSA office
Thur 1 July	:	CPATSA. Visits to Bebedouro Experiment station and Irrigation Scheme, and CPATSA dry land utilization experiments.
Fri 2 July	:	CPATSA office. Free after 11 am. (Footballmatch)
3/4 July	:	Weekend
Mon 5 July	:	CPATSA office. Free after 11 a.m. (football match)
Tue 6 July	:	By car to Vaza-Barris irrigation scheme, near Cocorobô, state of Bahia
Wed 7 July	:	At Vaza-Barris irrigation scheme
Thur 8 July	:	Return to Petrolina
Fri 9 July	:	CPATSA office. Presented a seminar for staff on: Salinity control and leaching requirements in irrigated soils.
10/11 july	:	Weekend
Mon 12 July	:	By car to São Gonçalo irrigation scheme, near Souza - Paraiba
Tue 13 July	:	São Gonçalo irrigation scheme
Wed 14 July	:	By car to Condado. Visit Eng.º Arcoverde irrigation scheme. Proceed to Campina Grande. Visit to Univ. Fed. da Paraiba - CCT.

Thur 15 July	: By car to Sumé. Visit Sumé irrigation scheme. Return to Campina Grande. Visit to Univ. Fed. da Paraiba - CCT.
Fri 16 July	: By car to Recife. Local public holiday. Used this day and the weekend to prepare, together with Engº Gilberto Gomes Cordeiro, a paper for
17/18 July (Weekend)	presentation on the 1st Sympósio Brasileiro do Trópico Semi-Arido, on the influence of the irrigation on the salinization and sodification of soils in the São Gonçalo irrigation project.
Mon 19 July	: Visits to IPA and EMBRAPA-SNLS, Recife. By car to Arcoverde.
Tue 20 July	: By car to Moxotó irrigation scheme and visit scheme. Proceed to Serra Talhado, visit IPA Exp. station there. Proceed to Petrolina.
Wed 21/Fr 23 J	: CPATSA office
24/25 July	: Weekend
Mon 26 July	: By car to Fortaleza
Tue 27 July	: DNOCS - Central administration
Wed 28 July	: By car to Pentecostes. Visit fazenda experimental Univ. Fed. do Ceara in Curú irrigation scheme. Return to Fortaleza
Thur 29 July	: By car to Morada Nova. Visit Morada Nova irrigation scheme. Proceed to Milagres.
Fri 30 July	: By car to Petrolina
31 July/1 August	: Weekend
Mon 2/Fr 6 Aug.	: CPATSA office
7/8 August	: Weekend
Mon 9/Fr 13 Aug.	: CPATSA office
14/15 August	: Weekend. Travel by bus to Recife
Mon 16/Fr 20 Aug.	: Attend 1st Symposium on Semi-arid Tropics at Olinda (Recife). Presented a paper together with Gilberto G. Cordeiro, and gave a presentation on drainage and salinity problems in regions of the semi-arid tropics.
21/22 August	: Weekend
Mon 23 August	: Flight Recife to Salvador
Tue 24 Aug. 1982	: Flight Salvador to Amsterdam Varig RG 706