Research on water management of rice fields in the Nile Delta, Egypt

Research on water management of rice fields in the Nile Delta, Egypt

S. El Guindy and I.A. Risseeuw

Edited by
H.J. Nijland

Publication 41

International Institute for Land Reclamation and Improvement/ILRI
P.O. Box 45, 6700 AA Wageningen, The Netherlands 1987.

This publication is based on research done by:

The Drainage Research Institute/DRI
13 Giza Street, Giza
Cairo, Egypt

About the authors:

Dr. S. El Guindy is a senior research officer at the Drainage Research Institute, Cairo.

Mr. I.A. Risseeuw was Leader of the Dutch Resident Team at the Drainage Research Institute, Cairo, from 1977 to 1980.
At present, he is Deputy Director of the Government Service for Land and Water Use, P.O. Box 20021, Utrecht, The Netherlands.

Mr. H.J. Nijland was a member of the Dutch Resident Team at the Drainage Research Institute, Cairo from 1978 to 1982.
At present, he is senior Coordinator of International Affairs at the IJssel Lake Polders Development Authority, P.O. Box 600, Lelystad, The Netherlands.

© International Institute for Land Reclamation and Improvement/ILRI,
Wageningen, The Netherlands 1987.
This book or any part thereof may not be reproduced in any form without written permission of ILRI.

ISBN 90 70754 08 8

Printed in The Netherlands.

Foreword

Egyptian and Dutch scientists have been co-operating on research on water management in Egypt for more than ten years. This research is carried out under the auspices of the Egyptian-Dutch Advisory Panel on Land Drainage, a group of experts from both countries that provides unique guidance. The Panel regularly reviews the results of the joint investigations of drainage technology, the re-use of drainage water for irrigation, and the economic evaluation of drainage projects.

To combat waterlogging and salinization of its cultivated land, Egypt is now implementing the greatest drainage project in its history. One of the major problems of this undertaking is the water management of tile-drained rice fields. The prevalence of rice in the cropping pattern causes problems for water management and drainage. In rice fields, the presence of a subsurface drainage system that was installed for other crops causes substantial water 'losses' through the system and leads to large applications of irrigation water.

The resulting higher water duty leads to a higher drain discharge. This creates special conditions in tile-drained soils, conditions that have not been investigated elsewhere. This publication presents the results of a study that was conducted in both tile-drained and non-tile-drained rice growing areas. The findings have been used to formulate recommendations for better designs and better operation of subsurface drainage systems under these conditions.

We sincerely hope that this publication will be of help to those facing the problems of water management in tile-drained rice growing areas.

It is only due to the persistence of experts from both Egypt and The Netherlands that this publication could appear. We appreciate the cordial and generous co-operation among the institutes involved, i.e. the Drainage Research Institute of the Water Research Centre, Cairo, both under the Ministry of Irrigation, and the International Institute for Land Reclamation and Improvement, Wageningen, under the Dutch Ministry of Agriculture and Fisheries.

Dr. M.H. Amer
Director,
Drainage Research Institute

Dr. J.A.H. Hendriks
Director,
International Institute for
Land Reclamation and Improvement

Contents

Acknowledgements

This book contains the main results of a comprehensive study of the water management and drainage of areas with rice in the crop rotation.

The study was conducted in the Egyptian Nile Delta as part of the Joint Programme of Technical Co-operation between Egypt and The Netherlands. The two executive agencies chosen by the Egyptian-Dutch Advisory Panel on Land Drainage were the Drainage Research Institute (DRI), Giza/Cairo, Egypt, and the International Institute for Land Reclamation and Improvement (ILRI), Wageningen, The Netherlands.

The organizational and logistic requirements for the study were provided by DRI, or purchased with funds made available by the Directorate General of Development Co-operation (DGIS) of the Dutch Ministry of Foreign Affairs. The preparation and publication of the manuscript was co-ordinated by ILRI under the supervision of Dr. N.A. de Ridder, Head of Publication Department. His keen textual criticism and editorial insight gave the manuscript its definitive form.

This book could not have been realized without the help and co-operation of many people. The authors are very grateful for the constructive remarks and support of Dr. M. Hassan Amer, Director of DRI, and for the suggestions and constructive criticism of Dr. Mustafa M. El Gabaly, Chairman of the Egyptian-Dutch Advisory Panel on Land Drainage, and Dr. Mahfoos Abdullah, Head of the Soils Department of Cairo University, during the planning and reporting stages of the study.

Special acknowledgement is due to Messrs. F.M. Ramadan, Ahmed Morsi, Akmal Omara, Mohammed A. Abdel Khalik, W. van Schaik, and C.W.J. Roest, who participated in either routine observation programmes or analytical procedures at the DRI laboratories. Their assistance in collecting and processing the data is highly appreciated.

Finally, the authors wish to thank Mr. Anwar Hammad, owner of the undrained rice farm, and the many farmers they met in the Nokrashi and Basal areas, for giving freely and cheerfully of their time. By explaining what they considered a good or inadequate practice, and by supplying any other information required, these people made a most important contribution towards the success of the investigation programmes.

1 Introduction

Agriculture in Egypt is wholly dependent on irrigation from the Nile, except limited areas in the oases of the Western Desert, which are irrigated from groundwater resources (Figure 1.1). The irrigated land represents only 3 per cent of the country's total area of 1 million km^2.

From the days of the Pharaohs until the 19th century, basin irrigation was practised every August and September, when the Nile flooded its banks. The construction of the Nile barrages and a network of irrigation canals made perennial irrigation possible over part of the cultivated area. More water for irrigation became available with the completion of the old Aswan Dam in 1902. The construction of the Aswan High Dam

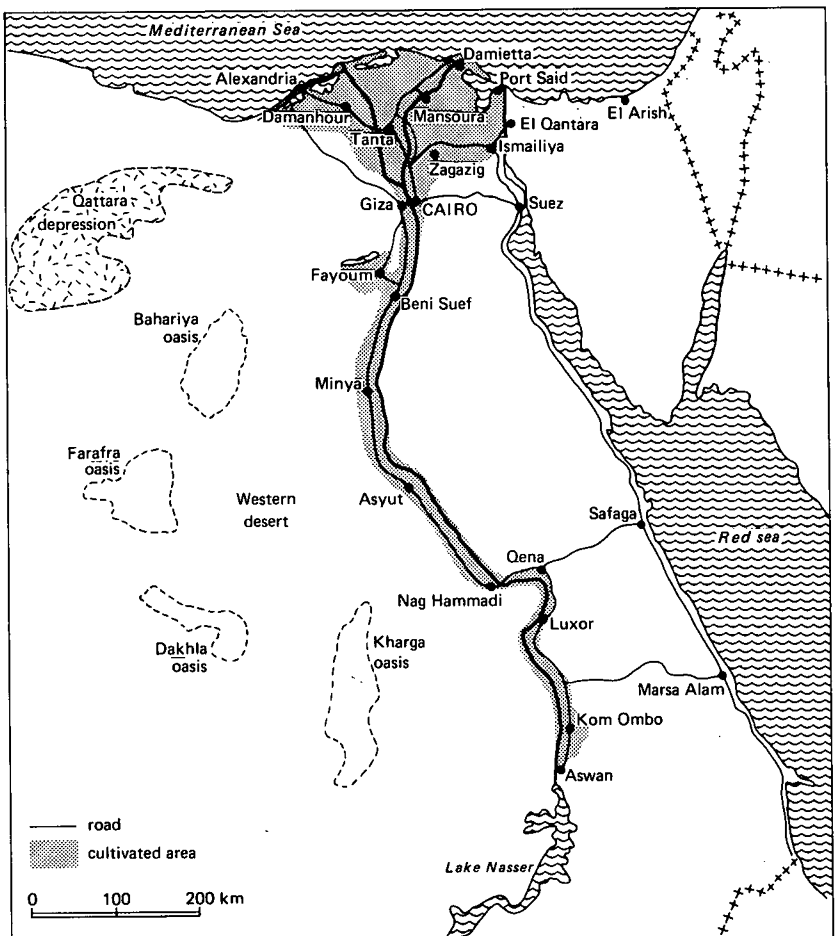


Figure 1.1 Cultivated areas in Egypt

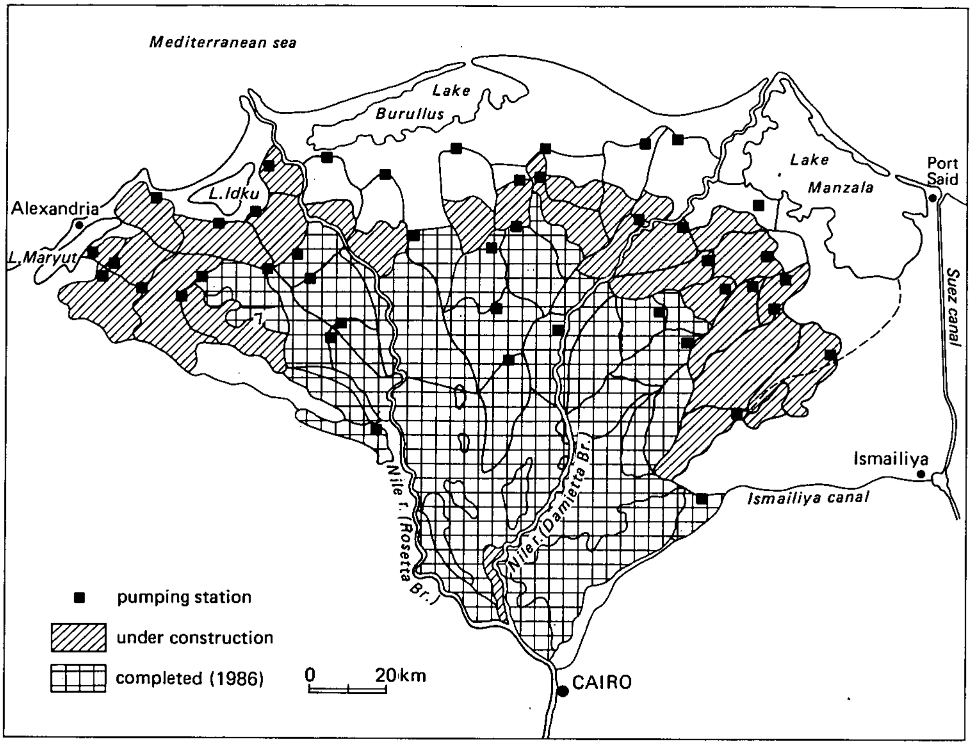


Figure 1.2 Location of the Nile Delta Drainage Projects

(1960-1967) finally eliminated the Nile's seasonal floods entirely and allowed all agricultural land to be brought under perennial irrigation. This meant that rice, among other crops, could be cultivated on a much larger scale than before.

Owing to the introduction of perennial irrigation, with its inherent percolation losses, the existing natural drainage gradually lost its ability to keep the watertable low enough to give good crop yields and, consequently, to maintain favourable salinity levels in the rooted soil layers. In arid climates such as Egypt's, high watertables cause salinization of the root zone. Without adequate drainage facilities, the accumulated salts cannot be leached from the root zone. To overcome these problems, a widespread system of open main drains and pumping stations was constructed. The installation of subsurface drainage systems was begun on a large scale in the 1970's, as the existing drainage system could no longer handle the rising watertables. Large parts of the southern and middle Delta have now already been drained (Figure 1.2).

The installation of subsurface drainage systems is primarily meant to improve the growing conditions of 'dry foot' crops such as cotton, maize, wheat, and so on. In Egypt, however, rice is grown in rotation with these crops, as a summer crop, following wheat or berseem. Rice cultivation is concentrated in the Nile Delta, with the main rice belt in the northern part; rice is the only submerged crop among the several 'dry foot' crops of this mixed cropping system.

The introduction of pipe drainage systems in the seasonal rice growing areas brought on water management problems.

During the growing season, the water management requirements in rice fields are clearly different from those in fields under other summer crops (mainly cotton and maize). This is true for irrigation as well as drainage. Fields under other than rice require control of the watertable, whereas rice fields are kept submerged for most of the growing season. In rice fields, the presence of a subsurface drainage system that has been installed for other crops causes substantial water 'losses' through the system, and leads to large applications of irrigation water. If the availability of irrigation water is limited, farmers commonly plug collectors with whatever means at hand, e.g. straw, mud, grass, sods. This undesirable, but logical, practice causes pollution of the collector downstream of the plug upon its removal, while the other crops upstream of the rice fields have no subsurface drainage at all, and may suffer from waterlogging.

In future, irrigation water will increasingly become a limiting factor for agricultural production. The extension of the irrigated areas in the deserts, such as West Nubariya near Alexandria, and in the Sinai near Port Said, will require extra irrigation water. Methods for a more efficient use of the water will become urgent and practical solutions are urgently needed to reduce the excessive irrigation water requirements of rice cropped land.

Until quite recently, planners of tile-drainage works in other arid and semi-arid regions had not been confronted with this problem. In most tile-drained areas rice is grown only in the initial phases of the reclamation of the saline soils and without rotation with other crops (Van Alphen 1975, 1984; Van de Goor 1967).

Subsurface drainage systems have been installed as an integral part of the drainage system in some rice growing areas of countries such as Japan, Korea, and China (Ezaki 1975; Tabuchi 1985; UNDP/FAO 1979a, 1979b; Soong 1985). However, rice is the sole crop during the summer season in these countries, and the purpose of drainage is mainly to improve farming practices (mechanization), and crop growing conditions for a second dry land crop. Closing devices (regulatory valves) constructed at the end of the drain lines control the drain outflow during the rice growing season. The climatological conditions for growing rice in these countries, temperate climates with high rainfall, differ from Egypt, with its arid climate and negligible rainfall.

Since there is no ready-made solution that might be applied to the Egyptian situation, the problem was tackled by conducting a study in tile-drained and non-tile-drained rice growing areas in the northern part of the Nile Delta, i.e. the Anwar Hammad farm, the Basal area (non-tile-drained), and the Nokrashi area (tile-drained). As very few quantitative data were available, investigations were directed towards gaining deeper insight into the nature and extent of the problems. The study included water management practices with respect to the water and salt balances of rice growing areas. One of the results of the study was to recommend modification of the layout of subsurface drainage systems in rice growing areas. The recommended concept of the drainage system (modified layout) was constructed and tested in a sizeable prototype area of 1700 ha, the Mahmudiya area, including the Mashtul pilot area.

We present some of the results of the studies in this publication, together with solutions for the design of subsurface drainage systems in rice growing areas.

2 Investigations

2.1 Introduction

Egypt has a warm and arid climate, with a short and mild winter. The mean monthly climatological data are presented in Table 2.1.

Table 2.1 Mean monthly climatological data

	Temperature January max.	min.	August max.	min.	Rainfall	Relative Humidity	Relative duration of bright sunshine	Evaporation*
	°C				mm/year	%	%	mm/day
Alexandria	18.5	9.3	30.6	22.8	191.8	65–72	63–89	1.6–7.5
Giza	19.5	6.4	34.4	20.4	20.2	53–73	68–86	1.5–7.7
Aswan	24.2	9.5	42.0	26.4	1.4	18–41		2.8–8.5

* Open water evaporation after Penman (E_0)
Source: Aboukhaled et al, 1975.

The soils in the Nile Delta are fine textured, medium heavy to heavy clays, becoming heavier towards the sea. There are two major cropping seasons with diversified cropping patterns: winter (November-May) and summer (May-October), and a less important 'nili' (named after the Nile flood) or late summer season (August-October). The major winter crops are wheat, barley, Egyptian clover or berseem, broad beans, vegetables. Summer crops are cotton, rice, and maize. The general practice is a 2 or 3-year crop rotation. In either case farming is intensive. Representative cropping patterns of a 3-year rotation are shown in Figure 2.1.

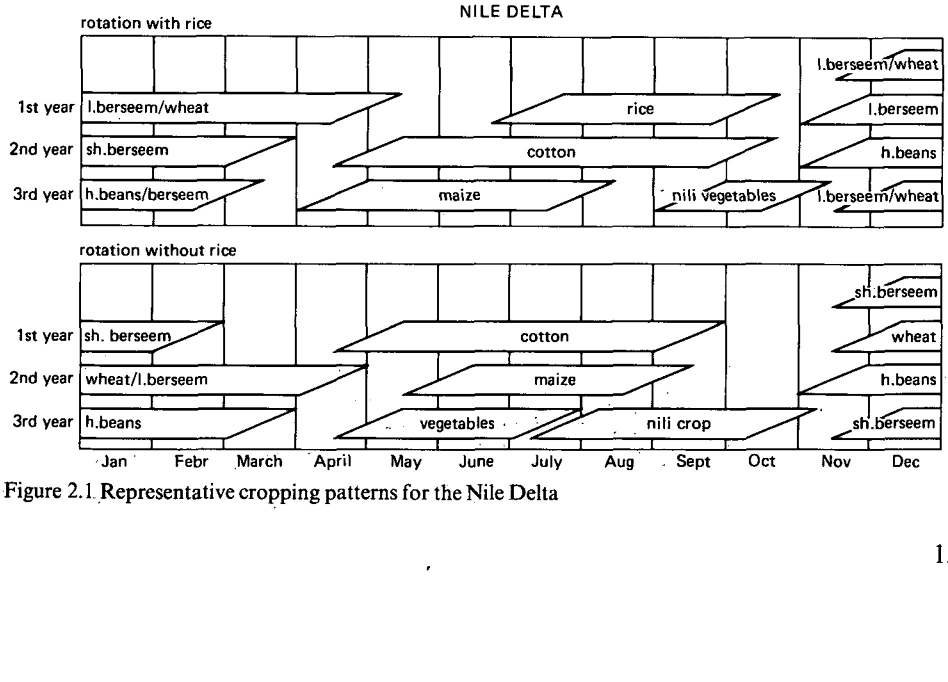


Figure 2.1 Representative cropping patterns for the Nile Delta

The average farm unit is about 1.5 ha, with over 90% of agricultural holdings below 2.1 ha. A farm is usually divided into as many plots as there are crops grown. However, the plots of one crop of different farms are generally combined into large units.

The areas planted with cotton and rice are largely controlled by the government, and they tend to be farmed in relatively large consolidated blocks. This facilitates land preparation, water distribution, and disease and insect control. The size of these cropping units varies from 2 to 80 ha, with an average size of 12 ha.

In the lower Delta, in places where the irrigation network supplies enough water, and where heavy fluvio-marine clays are present, rice predominates over maize as the summer cereal because soil salinity restricts yields of other crops. A typical cropping model for the northern Delta is presented in Table 2.2.

Table 2.2 Cropping model for the northern Delta

Winter season		Summer season	
Short Berseem	25%	Cotton	30%
Long Berseem	45%	Rice	45%
Wheat	25%	Maize	25%
Beans	5%		

Average crop intensity = 200%

2.2 Problem identification

The drainage system currently being installed in Egypt is a composite system; it is shown in Figure 2.2. Its main features are:

- The laterals are 8 cm in diameter and approximately 200 m long. They are laid at depths between 1.20 and 1.50 m, and their spacings are 40, 50, and 60 m. The drain pipes used for laterals were previously all made of concrete. These have been gradually replaced by PVC corrugated plastic pipes, which are installed by pipe-laying machines;
- The collectors are concrete pipes with diameters between 15 and 40 cm. The maximum depth of their outlets is 2.5 m. Collectors can be up to 2 km long;
- Concrete manholes, 0.75 to 1 m in diameter, which allow for direct visual inspection and cleaning of the system, are placed in the collectors at every third or fourth lateral.

The installation of subsurface drainage systems in the Nile Delta is primarily meant to ensure proper drainage and soil conditions for such crops as cotton, maize, wheat, and so on. In large parts of the Delta, however, rice is grown in rotation with these crops. As the rice fields are commonly submerged throughout the growing season, the introduction of a subsurface drainage system in these areas gives rise to severe problems such as:

- High percolation losses in rice fields to these drainage systems; if the system is left open, considerable amounts of water are lost through the tile drains, resulting in extremely high irrigation water applications;
- Farmers block the drainage systems (collectors) to reduce such losses, and this often causes severe clogging of the collectors;

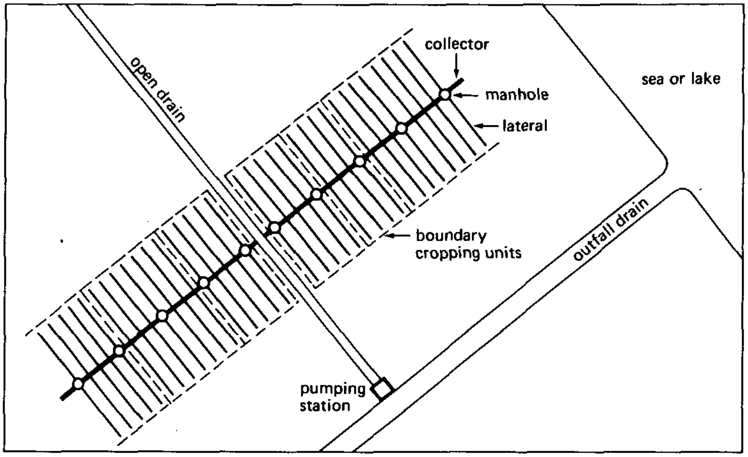


Figure 2.2 The drainage system being used in Egypt

- 'Over-pressure' developing in the upstream parts of the laterals/collectors, due to high discharges from downstream rice growing areas. This seriously limits water-table control in the area served by the collector, and results in poor drainage of the crops grown together with rice in the same collector area. The situation becomes worse if the rice fields are located in the downstream part of the collector area, and even more serious when the collector is blocked in order to reduce irrigation water applications for rice crops.

2.3 Objectives of the study

Measures were taken to achieve the following objectives:
- To obtain a better insight into the effects of the water management practices – as applied in recently subsurface drained areas by traditionally oriented farmers – on crop production and soil characteristics;
- To obtain a better insight into the effect of the more or less traditional water management practices on crop production and soil characteristics – as applied to non-subsurface drained rice areas;
- To determine the effects of this water management on the water and salt balance of the rice area;
- To produce optimal solutions and formulate design criteria for combined surface and subsurface drainage systems in areas where rice is included in the crop rotation.

2.4 Method of investigation

To achieve the above objectives three pilot areas were selected. They are: the Anwar Hammad farm, the Nokrashi area and the Basal area, all situated in the north-western part of the Delta (Figure 2.3). Of the three, only the Nokrashi area has a subsurface drainage system.

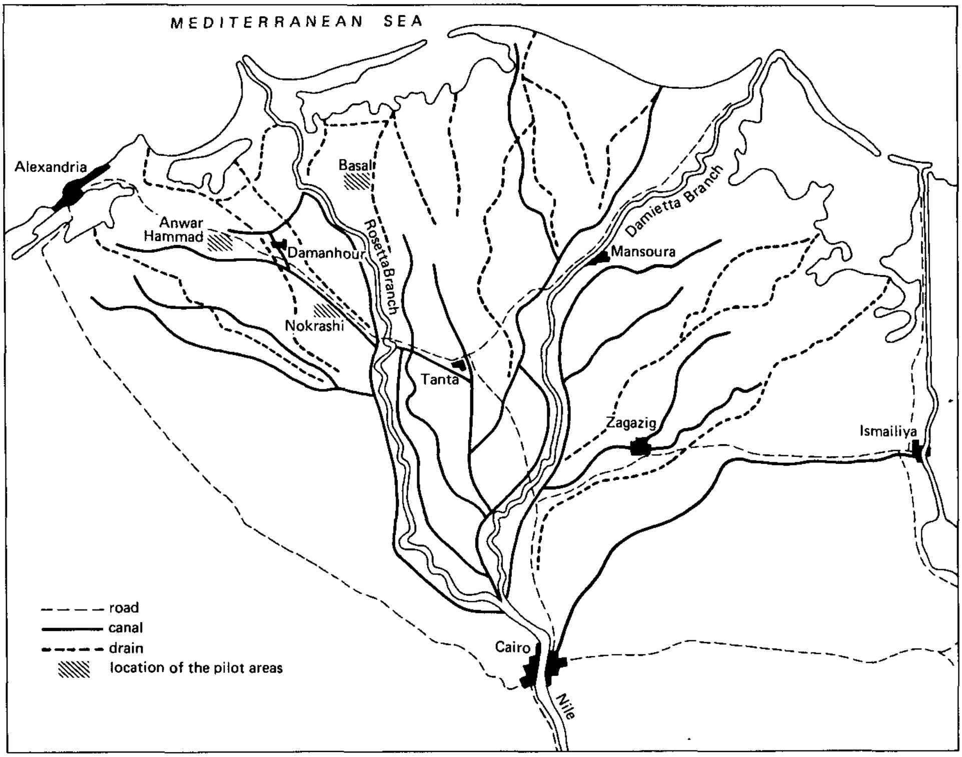


Figure 2.3 Location of the pilot areas

The investigation programmes in these areas included:
- Detailed soil surveys (texture, salinity, saturated paste percentage);
- Installation of piezometers;
- Measurement of the depth of the watertable;
- Measurement of the drain discharge (surface and subsurface) and its salinity;
- Determination of the depth, salinity, and temperature of the standing water layer;
- Determination of quality, availability, and distribution of the irrigation water;
- Collecting data on cropping techniques, crop logging, and crop production;
- Collecting meteorological data.

The general layout of the pilot areas and observation points are shown in Figure 2.4. The investigation programmes are conducted from 1977 until 1979, with the exception of the Basal area, where research was only carried out in 1979.

2.5 General description of the pilot areas

The gross and net cultivated acreages of the pilot areas are presented in Table 2.3. The soil surface of the pilot areas is relatively flat; the maximum difference in level is approximately 0.3 m. The levelled farm plots vary in size from 0.1 to 0.6 ha. These plots were not always sufficiently levelled; differences in levels of up to 6 cm occurred

Table 2.3 Acreages of the pilot areas in ha.

	Gross area	Net area
Anwar Hammad	16.9	14.1
Nokrashi I	24.5	22.5
Nokrashi II	30.3	27.5
Nokrashi III	18.0	16.2
Basal	29.9	27.2

in some cases. The rice is irrigated from tertiary irrigation canals, in which the water level is 0.5 to 1.0 m below the soil surface. The water is lifted from these canals by sakkias, or water wheels, driven by animal traction (Figure 2.5), or by motor pumps.

The water is supplied to the plots via high-lying field ditches. In the summer the tertiary canals receive water on a rotational schedule: four days on and four days off. The winter rotation is 7 days on and 7 days off. Details of the layout of the irrigation and drainage system are shown in Figure 2.6.

The field drains in the surface drainage system serve all the plots. These drains remove the surface drainage water by gravity flow via open tertiary collector drains to public drains. The field drains are approximately 0.50 m deep.

The laterals of the subsurface drainage system in the Nokrashi area discharge into the main collector at a depth of about 1.20 m. The average bottom depth of the collector is 1.70 m. The distance between the laterals is 40 m.

The soil profile at the Anwar Hammad farm consists of a layer of heavy clay, approximately 2 m thick, which overlies a low permeable layer of greyish clay, rich in carbonate, approximately 1 m thick. The upper 50 cm of the soil profile contains on average 80% clay and the rest silt. The soil salinity ranges from 4 to 10 mmhos/cm. The permeability is low, 0.03 to 0.15 m/day.

The soils in the Nokrashi area are also heavy clay soils. The upper 50 cm of the profile contains on average 55% clay, 35% silt, and 10% fine and very fine sand. The soils in this area are non-saline. The average salinity level varies from 2 to 4 mmhos/cm. The permeability ranges from 0.02 to 0.15 m/day.

The silty clay soils in the Basal area contain on average nearly 50% clay and the rest silt. The soil salinity in the area varies from 3 to 5 mmhos/cm.

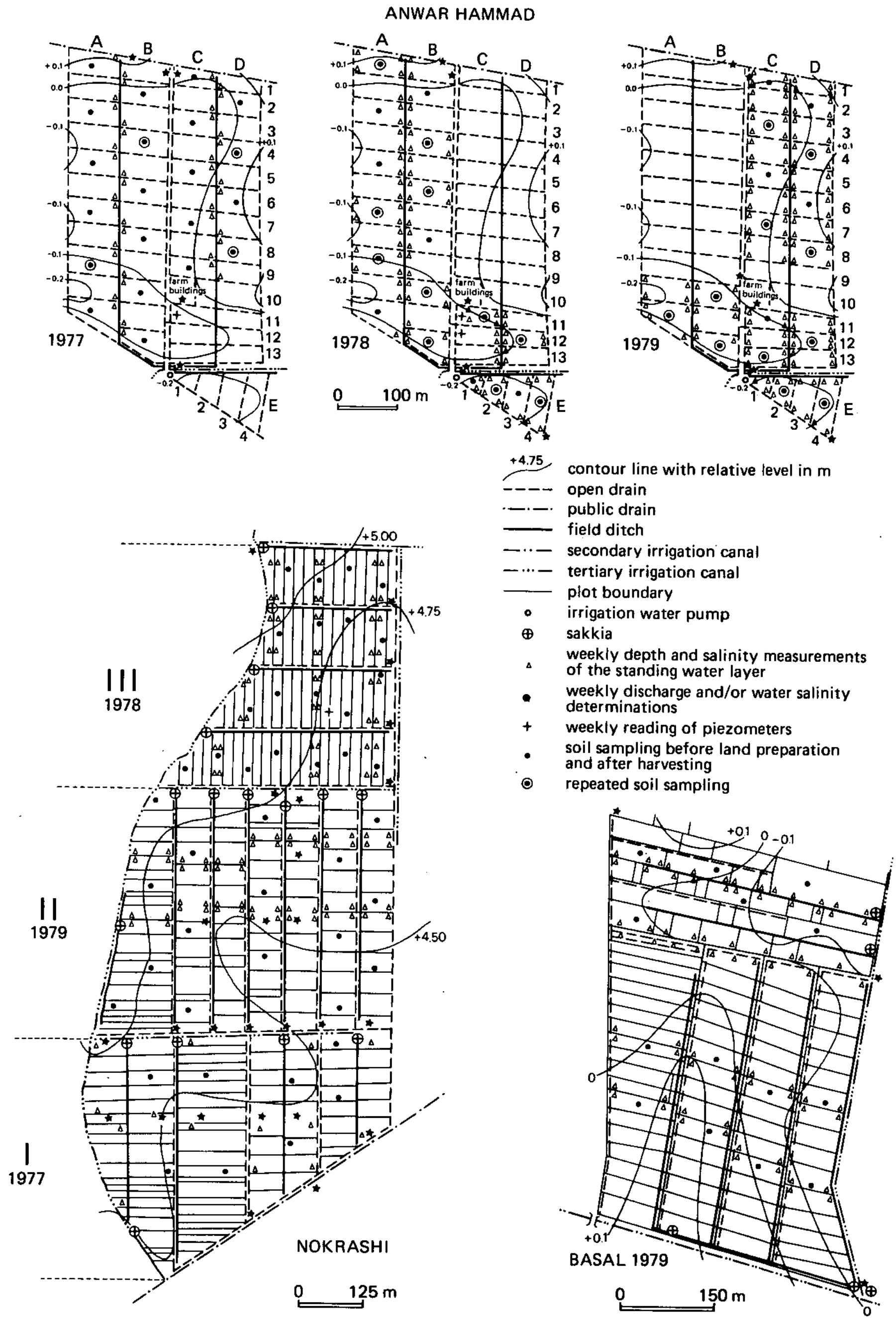


Figure 2.4 General layout of the pilot areas and observation points

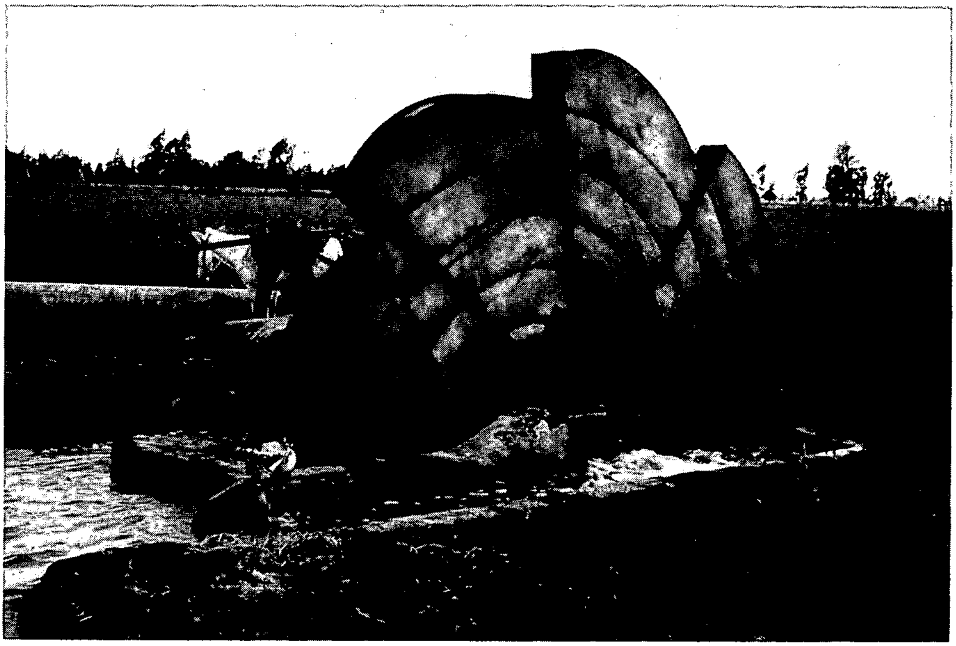


Figure 2.5 Sakkia

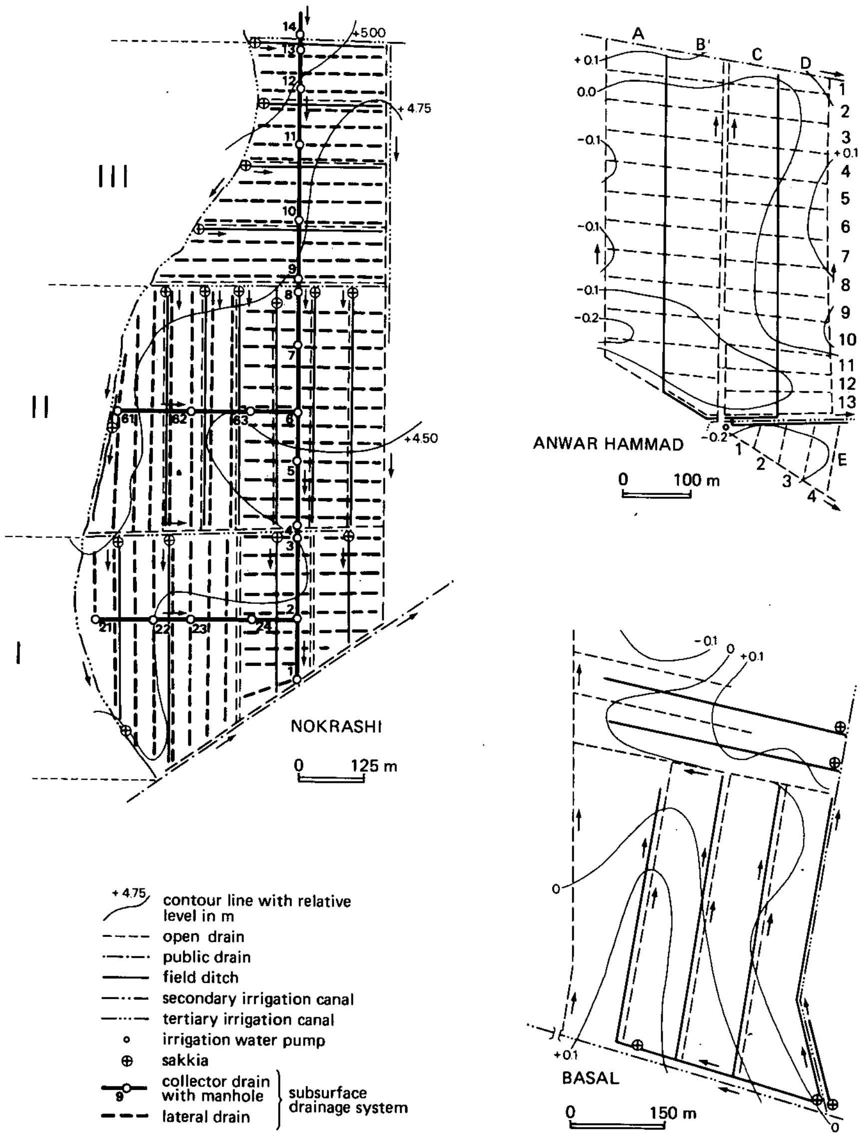


Figure 2.6 Layout of the irrigation and drainage system in the pilot areas

3 Results

3.1 Rice cultivation practices

3.1.1 General

Field observation in the pilot areas indicated that Nahda was the main rice variety planted. The Giza 159 variety was also planted, but was of only minor importance. Both varieties are of the japonica type.

The rice was seeded in nurseries during May, and transplanted to the farm plots in late June or early July. Harvesting took place in October/November.

Fertilizers were applied two or three weeks after the rice was transplanted and during panicle initiation. Only nitrogen fertilizers were used, either in the form of urea or ammonium sulphate. The surface water of the fields was drained off into the surface drainage system prior to fertilization. One or two days later, the fields were flooded once more. Weeding was done shortly after the N-dressing. Two weeks before the harvest, surface drainage was practised to stimulate the ripening of the crop and improve the accessibility of the land. Harvesting was carried out using sickles.

Rice cultivation covered approximately 65% of the plots at the Anwar Hammad farm, while cotton was grown on the remaining plots. The cropping pattern in the winter season included berseem (45%) and barley (15%); part of the farm was left fallow because of (high) soil salinity levels. The plots cultivated with rice changed in the Nokrashi area according to the crop rotation schedule of rice followed by cotton and maize in subsequent summer seasons (Table 3.1).

Table 3.1 Summer crop rotation schedule in the Nokrashi area

Subarea	Rice	Cotton	Maize
Nokrashi I	1977	1979	1978
Nokrashi II	1979	1978	1977
Nokrashi III	1978	1977	1979

The sub-areas Nokrashi I, Nokrashi II, and Nokrashi III formed 'one crop' consolidated units in the summer season. Wheat (33%) and berseem (67%) were the most important winter crops, preceding the rice.

All the plots in the Basal pilot area were completely covered with rice during the 1979 summer season.

3.1.2 Rice nurseries

The rice season starts in May with the preparation of small nurseries along the length of the field ditches (Figure 3.1). The total nursery area covered 10 to 15% of the area

Figure 3.1 Rice nurseries

finally planted with rice. The surface water layer on the nurseries was kept at approximately 5 cm. The water layer in each nursery was refreshed completely in the early morning hours by first draining off the remaining standing water. The nursery was then refilled.

Water temperature in the nurseries at the Anwar Hammad farm was high, often reaching 35°C, especially in the first few weeks, when the water was not yet shaded by the rice plants. The irrigation water used for refreshing was also at a high temperature. Temperatures between 28 and 32°C were often recorded.

Fertilizer in the form of ammonium sulphate and/or urea was added to the nurseries at a rate of 40 kg N/ha. Fertilizer was applied at a rate of 65 kg N/ha at the Anwar Hammad farm.

The seedlings were ready for transplanting after 30 to 40 days.

3.1.3 Land preparation

The farmers recognized the need for levelled land for submerged rice cultivation. After the dried and deeply cracked soil was loosened with a chisel cultivator, they usually tried to 'level' their basins under flooded conditions before transplanting the rice seedlings. Irrigation water was supplied to the plots until the soil was fully saturated and a small water layer was established on the field. Using the water level as a guide, the soil was levelled and automatically somewhat puddled by dragging a heavy timber over the muddy soil (Figure 3.2). At the same time, the old levees around each plot were reconstructed at a height of about 15 cm above soil level. Levelling also aimed

Figure 3.2 Land preparation of the rice fields

at creating a slope of about 5 cm per 100 m in the soil surface of each plot, the lowest part being near the surface drains in order to promote quick drainage of the surface water layer.

The 'puddling' was not very intensive. The bulk density of the topsoil after the wet levelling was more or less the same as that of non-puddled clay soils; moreover, the average water content of the 'puddled' soil was considerably less than that of the saturated paste. Effective puddling would have increased the bulk density (Wickham and Singh, 1978).

There was no essential difference in soil preparation in all three pilot areas. The results of the wet levelling, however, were not the same. On most plots of the Nokrashi area and Anwar Hammad farm, the land levelling operations were rather unsatisfactory. At the Anwar Hammad farm differences in land height within a single plot of more than 6 cm were observed, while in the Nokrashi area the large number of internal levees within most plots indicated that land levelling operations could be improved considerably. In the Basal area, the land levelling had been carried out properly.

3.1.4 Crop development at transplanted rice plots

The density of the transplanted rice seedlings was 16, 18, and 32 hills per m^2 at Anwar Hammad farm, Nokrashi, and Basal area, respectively. The respective average number of panicles per m^2 was 335, 600, and 725, for the three areas.

Crop development was mostly normal and homogeneous on each of the rice plots in the Nokrashi and Basal areas. Due to the high topsoil salinity at the Anwar Hammad farm, a considerable number of rice hills died and an irregular crop stand was observed. In general, the crop along the field ditch was 20 to 30% taller than the crop near the field drain (Figure 3.3).

The rate of fertilizer application in the Basal area was twice that for the Nokrashi area and the Anwar Hammad farm (Table 3.2).

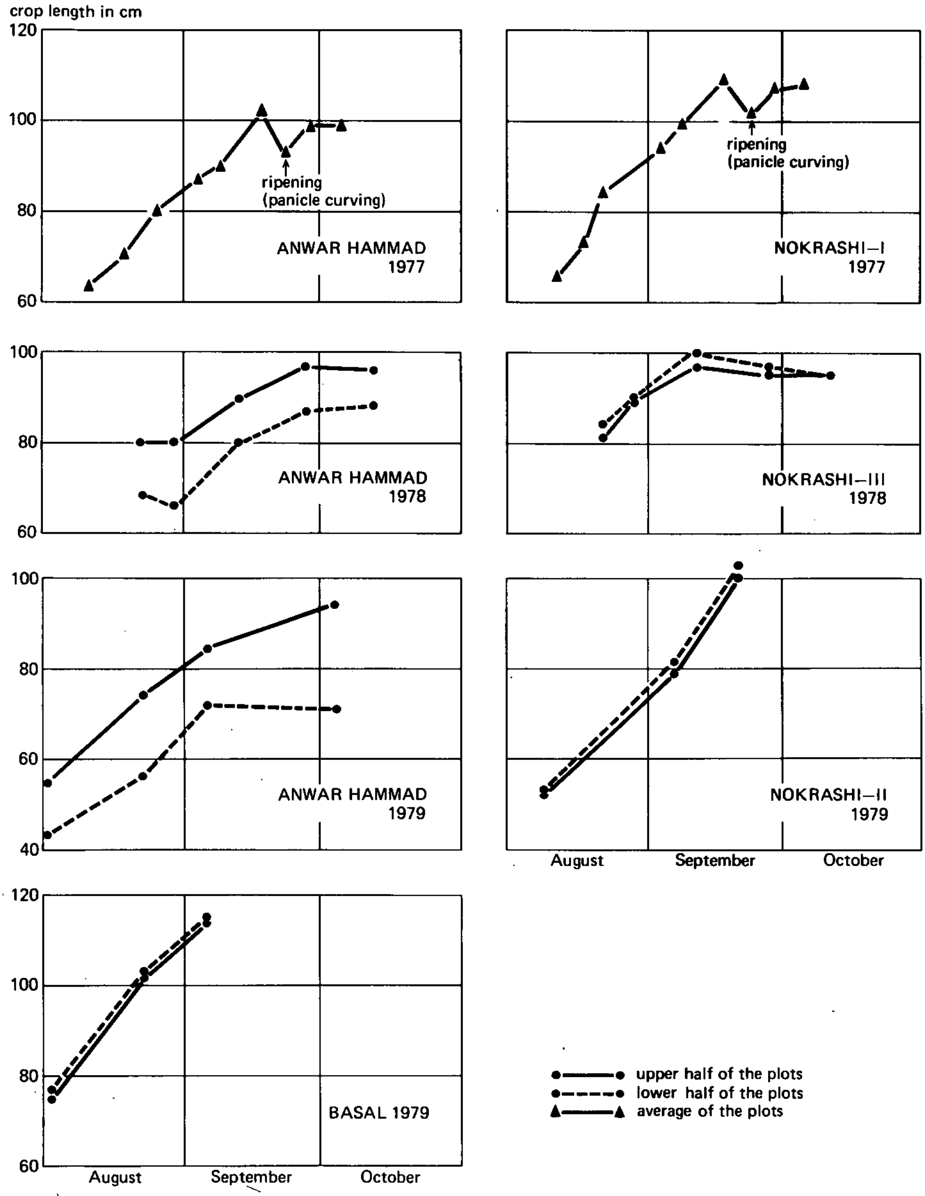


Figure 3.3 Average crop length

Table 3.2 Rate of fertilizer application in kg N per ha

Anwar Hammad farm	50– 70
Nokrashi area	50– 80
Basal area	125–150

3.1.5 Crop yields

Because of the striking differences in the development of the rice crop at the lower and higher parts of most plots at the Anwar Hammad farm, the crop yields were usually not determined per plot, but per plot section (Figure 3.4). Table 3.3 shows the average grain yields per plot section and the resulting average production per pilot area.

The yields at the Anwar Hammad farm in the upper sections of the plots were considerably higher than in the lower sections. On average, differences of 65 to 100% were determined between both sections. The production levels per plot are presented in Figure 3.5.

Rice yields in the Nokrashi area and Basal area were significantly higher than at the Anwar Hammad farm. Yield differences between the upper and lower halves of the plots in these areas were of minor importance (3–14%), as the observed regular crop growth already indicated.

Figure 3.4 Cutting of rice to assess crop production

Table 3.3 Rice production, grain yields per plot sections, and per pilot area in ton/ha

Area	plot section			
	upper-third	middle-third	lower-third	area
Anwar Hammad farm				
1977				3.1
1978	5.6	4.5	3.4	4.5
1979	4.1		2.0	3.1
Nokrashi area				
1977				6.5
1978	6.9		6.7	6.8
1979	6.1		6.6	6.3
Basal area				
1979	6.8		7.7	7.3

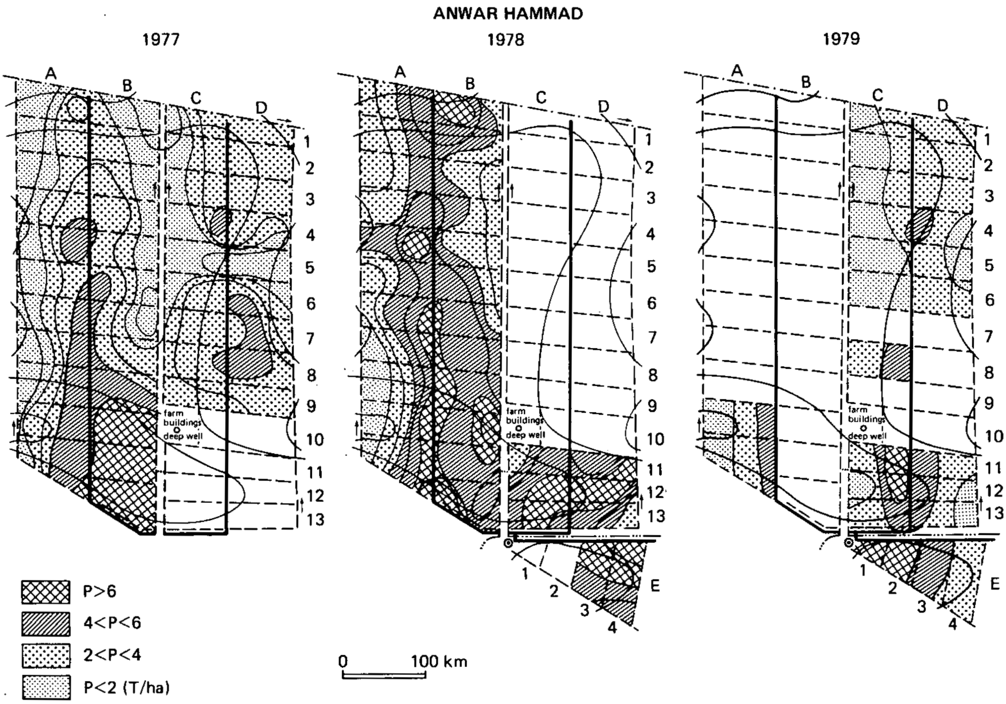


Figure 3.5 Rice production levels per plot at the Anwar Hammad farm

3.2 Soil salinity

The average EC_{ex}-values at the beginning (June) and end (November) of the rice growing season are presented in Table 3.4.

A modest desalinization of the soil profile was observed at the end of the rice season. The soil salinity had dropped only slightly in the non-saline Nokrashi area.

Table 3.4 Average EC_{ex}-values at the start (June) and at the end (November) of the rice growing season

		EC_{ex} (mmhos/cm) of the soil layers (cm)							
		00–25		25–50		50–75		75–100	
Area		June	Nov	June	Nov	June	Nov	June	Nov
Anwar Hammad									
	1977	6.4	4.1	8.1	5.8	7.2	5.5	6.5	4.7
	1978	6.9	4.3	7.2	6.0	6.5	6.0	6.7	5.4
	1979	6.6	7.0	8.3	9.7	5.6	7.9	4.2	5.4
Nok I	1977	1.8	2.2	2.0	1.7	2.1	1.8	2.8	2.3
Nok III	1978	1.3	1.2	1.4	1.2	1.6	1.3	1.8	1.4
Nok II	1979	5.0	3.2	4.1	2.4	4.7	3.3	4.0	3.2
Basal	1979	3.8	3.1	4.8	3.6	5.1	4.2	4.9	4.1

At the end of the 1979 rice season the soil salinity had increased at the Anwar Hammad farm. In that season the availability of irrigation water was far from satisfactory in June and July. When water was in short supply the soil profile could no longer be completely saturated. The downward flux reversed and an upward flux of saline groundwater ensued. It apparently caused considerable resalinization of the soil profile in these months. Following this, sufficient irrigation water could not leach enough salts from the soil profile to attain a negative salt balance at the end of the rice season. The topsoil salinities (0-15 cm) at harvesting are presented in Figure 3.6.

Topsoil samples (0-25 cm) were frequently taken during the 1978 rice season to monitor the de- or resalinization of this soil layer. The data are plotted in Figure 3.7. It is obvious that an increase in the salinity of the topsoil occurs after the rice harvest. The plots C11, D12, E2, and E4 had already dried and cracked somewhat, by the time they were sampled in November 1978, roughly two weeks after the start of the rice harvest.

Consequently, the clearly demonstrated desalinizing effect of rice on the topsoil salinity had already reversed, and salinization was again taking place through capillary rise of water and salts from the still very moist and saline deeper soil layers.

The soil salinity was also monitored during the following winter and summer seasons. The changes in soil salinity can clearly be seen from Figure 3.8. The figure shows that a considerable resalinization of the soils took place when non-rice crops were grown, especially cotton, at the Anwar Hammad farm (non-tile-drained).

Berseem cultivated after cotton induced soil desalinization. The soils were deeply cracked after cotton cultivation, and irrigation water was able to leach the salts of

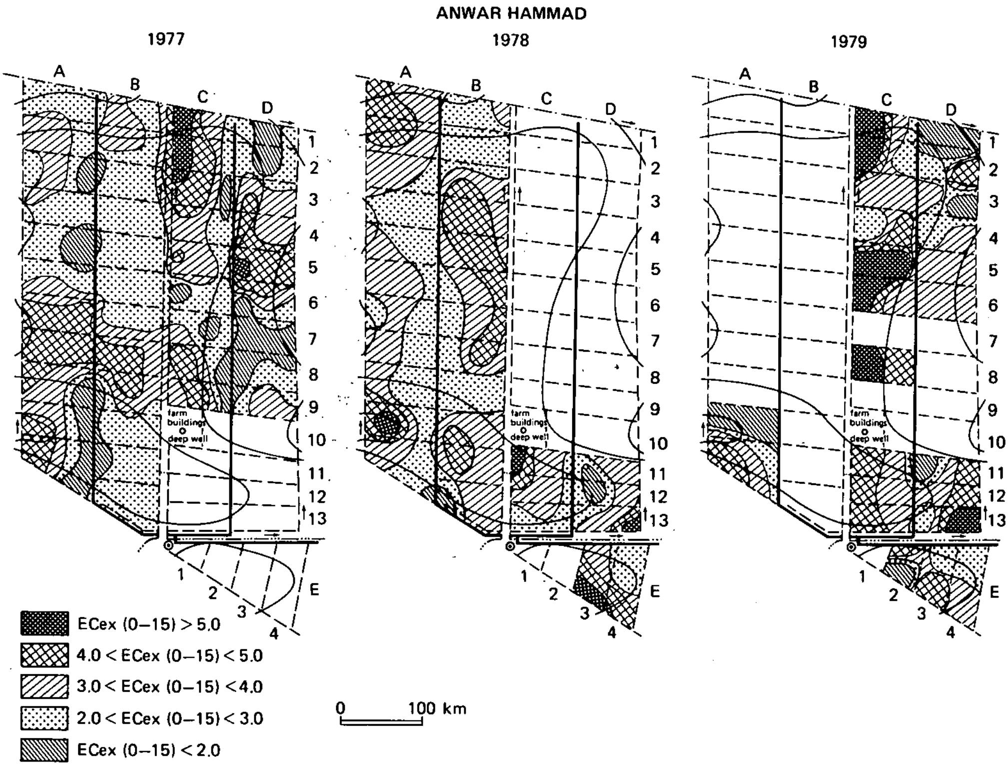


Figure 3.6 Topsoil salinities (0-15 cm) at the Anwar Hammad farm during harvesting

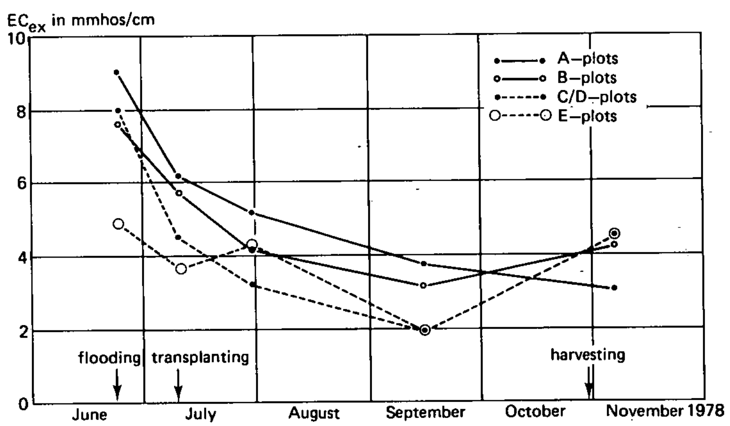


Figure 3.7 Average soil salinity (EC_{ex} in mmhos/cm) of the soil (0-25 cm) at the Anwar Hammad farm during the 1978 rice season

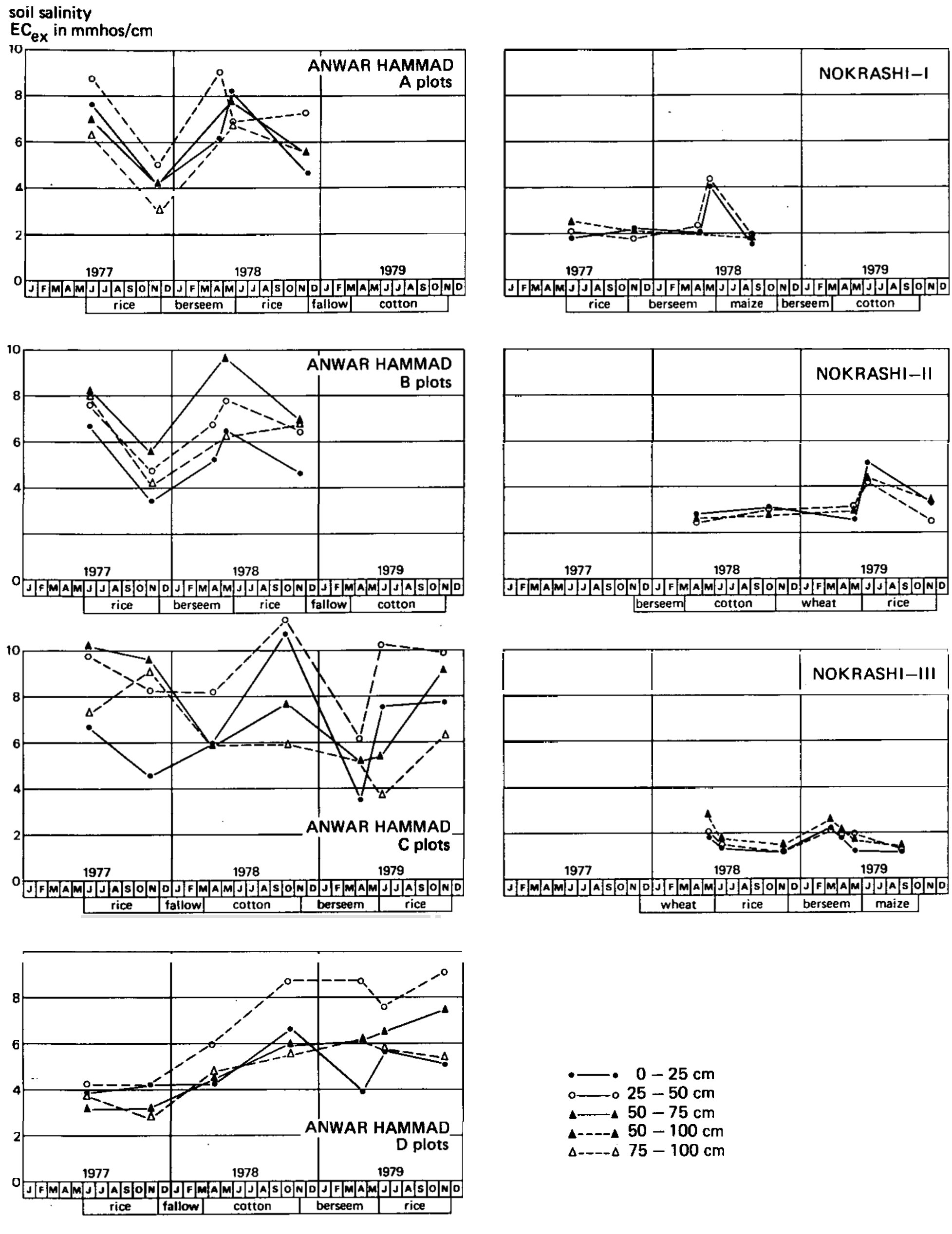


Figure 3.8 Soil salinity (0-100 cm) at the Anwar Hammad farm and in the Nokrashi area during the period 1977-1979

the top layers through these cracks. Berseem grown after rice did not exhibit this, as it was sown when the rice was ripening on the field and the soils were still saturated. Also in May, when the berseem was ripening, salinization apparently took place through capillary rise of water and salts.

The seasonal variations in soil salinity in the Nokrashi area were very small. The salinity in Nokrashi II area was higher than in Nokrashi areas I and III. This was probably due to the fact that the subsurface drainage systems in the Nokrashi II area were not functioning properly.

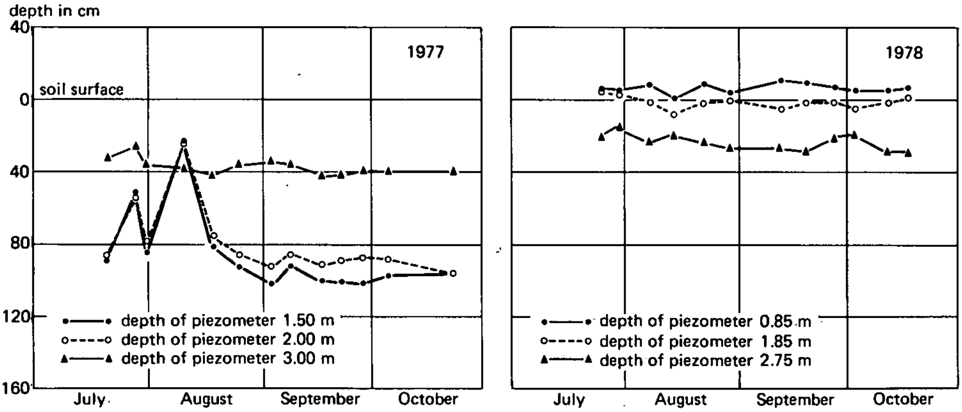
Soil resalinization when non-rice crops were grown was remarkably less than at the Anwar Hammad farm. Nevertheless, the figures consistently show that the soils are slightly resalinized at the transition from winter to summer cropping season. At that time, the soils are not irrigated for shorter or longer periods, depending on the crop rotation, and evaporation rates are high.

3.3 Groundwater

Weekly readings of the piezometers in a cotton field at the Anwar Hammad farm showed a head difference of about -50 cm between the top layer and the layer below the low permeability layer of grayish clay (Figure 3.9a). The water level in the shallow piezometer was about 85 cm below the soil surface against 35 cm in the deepest piezometers, indicating an upward flow of groundwater in areas of the farm where non-rice crops were grown.

The weekly reading of the piezometers on the same spot, but now covered with a rice crop, showed that the watertable was near the soil surface. A head difference of about +25 cm existed with respect to the subsoil layers at 2.50 m depth. This indicates a downward movement of the groundwater (Figure 3.9b).

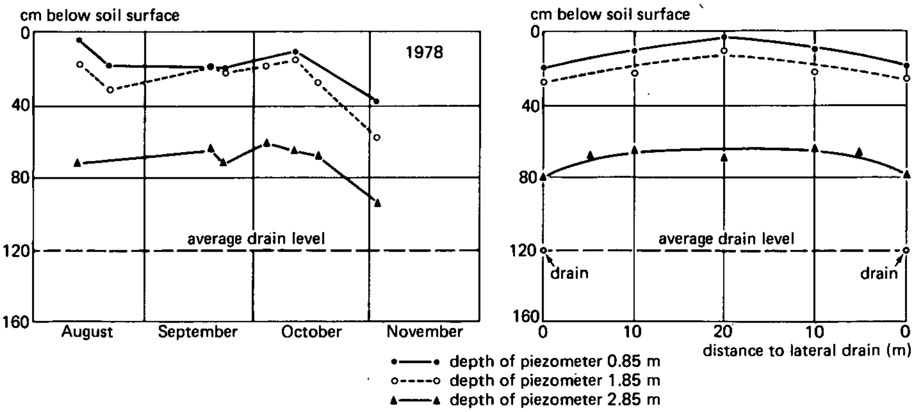
Multiple piezometers were placed in a row perpendicular to two laterals in the Nokrashi area. Figure 3.10 shows the average watertable levels at the observation points.



a) Water levels in piezometers installed in a cotton field

b) Water levels in piezometers installed in a rice field

Figure 3.9 Groundwater hydrograph of cotton field (a) and rice field (b) at the Anwar Hammad farm



a) Water levels in piezometers installed in a rice field

b) Average water levels during the rice growing season in piezometers installed in a rice field, between two lateral drains

Figure 3.10 Groundwater hydrographs in the Nokrashi III area

The watertable is near the soil surface. The head differences indicate a completely saturated soil profile, a permanent downward movement, and a flow to the lateral drains. After the irrigation stopped in October, the watertable gradually fell to the drain level.

3.4 Water management practices

3.4.1 Subsurface drainage system

The subsurface drainage system in the Nokrashi area was temporarily blocked by the farmers at the end of the transplanting of rice until the end of July. This was done because of shortage of irrigation water. In this way high percolation losses could be prevented, so that the plots would not dry out.

The blocking of the subsurface drainage system was done by closing the collector outlet at the manhole at the point in the consolidated rice area that is furthest downstream, e.g. manhole 9 in Nokrashi III. The farmers used clay, straw, and broken tile drains to close the outlets. An undesirable result was that parts of the collector gradually silted up over time, reducing its transport capacity considerably.

In 1977, 1.5 years after the installation of the subsurface drainage system, high lateral and collector discharges were measured in the Nokrashi I area. Figure 3.11 shows a V-notch measuring weir at the collector outlet of the subsurface drainage system. The collector discharge averaged 7 mm/day in August; following this, the discharge gradually decreased from 6 mm/day in September to 2 mm/day at the end of October (Figure 3.12). In 1978 the collector discharge in the Nokrashi III area was considerably less, 1.5 to 2 mm/day (Figure 3.13).

Figure 3.11 V-notch measuring weir at the collector outlet of the subsurface drainage system

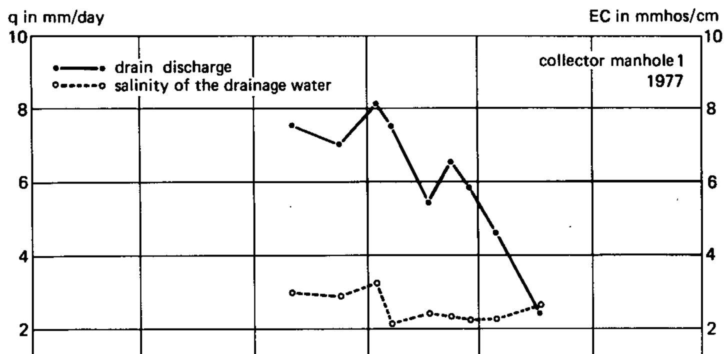


Figure 3.12 Collector discharges and salinity of the drainage water in the Nokrashi I area, 1977

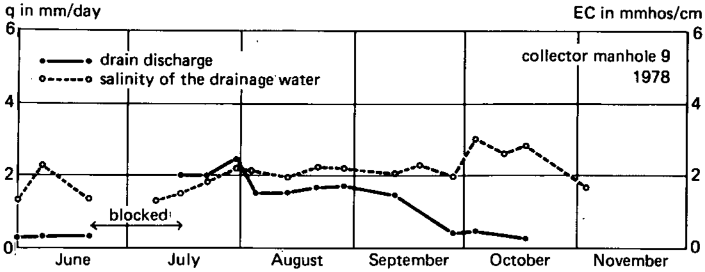


Figure 3.13 Collector discharges and salinity of the drainage water in the Nokrashi III area, 1978

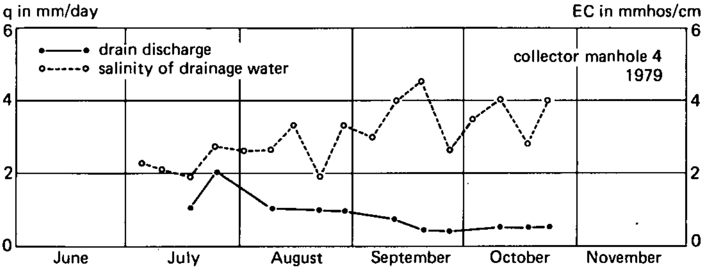


Figure 3.14 Collector discharges and salinity of the drainage water in the Nokrashi II area, 1979

Reduced collector discharges were also measured in the Nokrashi II area, 1979; the average discharge was about 1 mm/day (Figure 3.14). The average discharges of the laterals varied from 0.5 to 4 mm/day (Figure 3.15). The plotted discharge values represent instantaneous measurements. The salinity of the drainage water varied from 1 to 10 mmhos/cm. As may be expected the salinity generally increased at low discharges.

Drain discharges were also measured in non-rice growing plots. The (sub)collector discharges of fields grown with wheat, berseem, cotton, or maize seldom exceeded 1.5 mm/day.

3.4.2 Surface drainage

If enough water is available at the Anwar Hammad farm it is common practice to flush the surface water layer of recently levelled plots, before the rice is transplanted. The aim is to reduce topsoil salinity. During periods of water shortage, after planting the rice, the open field drains were closed to minimize water losses. As soon as an ample water supply was available once more, generally from the beginning of August, each plot was completely drained once every 8-12 days, and a fresh layer of surface water was restored over the next 24 hours.

The surface drains in the Nokrashi area conveyed mainly lateral seepage losses of surface water through the field bunds. In the Basal area surface drainage was carried out less frequently, probably due to the better water quality, which allowed for less

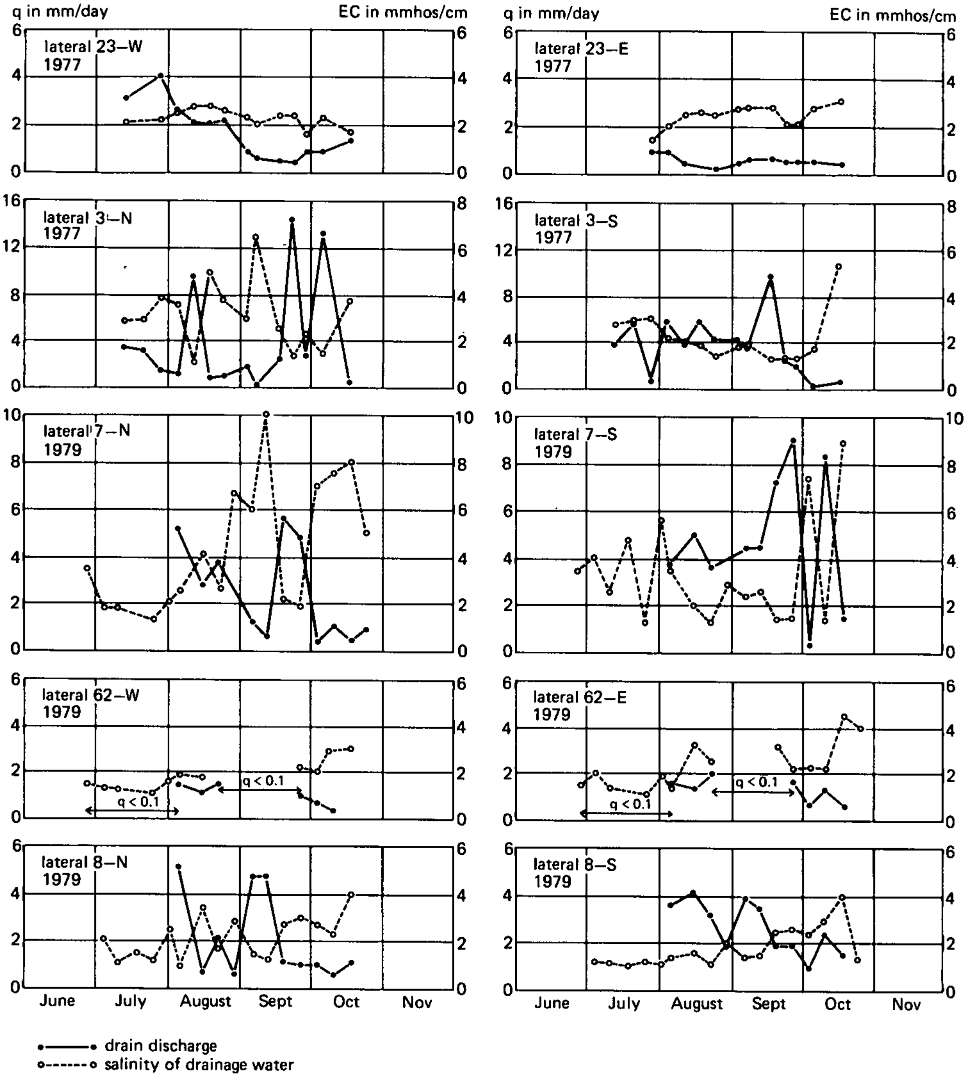


Figure 3.15 Discharges of laterals and salinity of the drainage water in the Nokrashi area in 1977 and 1979

frequent refreshment of the surface water layer; using fresh water to top-up the surface water layer appeared to be sufficient to maintain the salinity of the standing water layer within acceptable limits.

3.4.3 Irrigation

Shortage of irrigation water was generally felt during the transplanting period in the Nokrashi area and at the Anwar Hammad farm. The availability of a motor pump at the Anwar Hammad farm made it possible to reduce the negative effects of water shortage to some extent, as still water could be pumped from the irrigation canal during off-turn periods. When the water level in the irrigation canal was too low for the sakkias to lift irrigation water efficiently in the Nokrashi area, the farmers hired motor pumps. Sometimes, even surface drainage water from upstream areas was used to overcome water shortages. This was detrimental to the quality of the irrigation water.

In the Basal area irrigation water of good quality was available in abundance.

The total amount of irrigation water and its quality applied to the pilot areas during the rice season are presented in Table 3.5. The figures compare rather well with those reported by the Egypt Water Use Management Project (EWUP); total water applications during the rice season in the well-watered Abu Raia area near Kafr el Sheikh ranged from 1140 to 2100 mm. Measured average total water applied was 1610 mm (Metawie et al. 1981).

Table 3.5 Irrigation water applications and qualities in the pilot areas during the rice season

Region		Irrigation water	
		Total application mm	Salt concentration in mmhos/cm
Anwar Hammad farm	1977	1450	0.7
	1978	1500	0.7
	1979	1340	0.8
Nokrashi	1977	1350	1.0
	1978	1270	0.4
	1979	1180	0.8
Basal	1979	1165	0.35

3.4.4 Surface water layer

The variations in depth of the surface water layer in rice fields were mainly due to the availability of irrigation water. Topping-up the water in the plots generally began when the depth of the surface water layer had fallen to about 3 cm. When irrigation water was easily available, topping-up or refreshing the surface water layer started earlier. The topping-up of the surface water layer was carried out until a depth of about 10 cm was reached. Figure 3.16 shows a staff gauge in a rice field, used to measure the depth of the surface water layer.

Figures 3.17a and 3.17b show the average depth and salinity of the surface water layer of the farm plots in the Nokrashi area and at the Anwar Hammad farm in 1977 and 1978. Figure 3.17a also shows the average temperature of the surface water layer. Figures 3.17c, 3.17d, and 3.17e present the average depth and salinity of the surface water layer in the upper half and the lower half of the plots in the three pilot areas during the 1979 rice season.

At the Anwar Hammad farm the surface water layer was approximately 1 cm deeper at the upper half of the plots (irrigation canal side) than at the lower half (drain side).

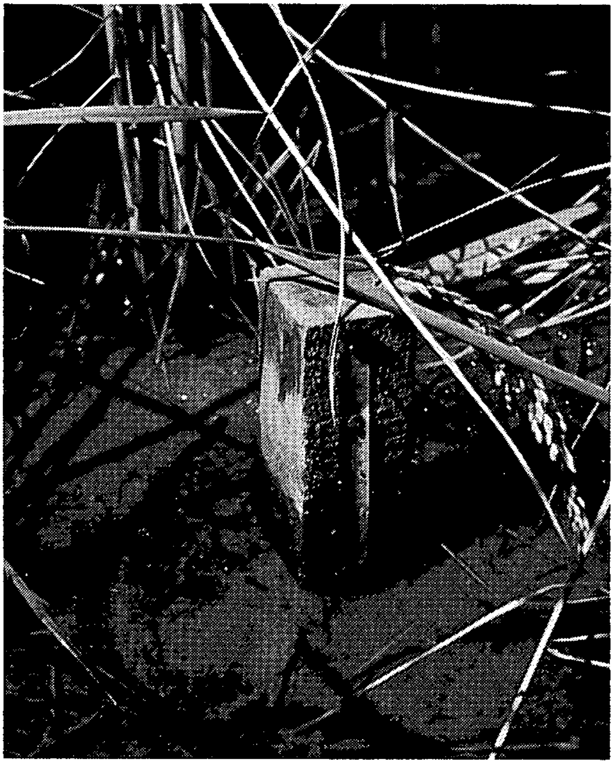


Figure 3.16 Staff gauge in a rice field, used to measure the depth of the surface water layer

This was mainly due to insufficient levelling of the plots (Section 3.1.3). In the other areas, Nokrashi and Basal, the water levels at the lower part of the plots were higher, in accordance with the slope of the plots. During the rice growing season the average depth of the surface water layer in the investigated areas was about 5 cm.

The salinity of the surface water layer differed considerably between the upper half and lower half of the plots (100 to 200%) at the Anwar Hammad farm. When the plots were drained off to enable refreshment of the surface water layer (Section 3.4.2) remnants of the (saline) water layer remained on the fields, mostly at the lower half of the plots, and contributed to the new water layer salinity.

Remnant saline water at the upper half of the plots flushed to the drain side of the plot when fresh irrigation water was let in. The higher topsoil salinity at the drain side of the plots is another factor (Sector 3.6.6). In the Nokrashi and Basal areas these differences were less, 10-15% and 40%, respectively. The lower topsoil salinity and better levelling might explain the difference with the Anwar Hammad farm. The average salinity of the standing water layer was respectively 1.7, 1.0, and 0.7 mmhos/cm at the Anwar Hammad farm, in the Nokrashi and the Basal areas.

The temperature of the surface water layer was rather high at the beginning of the rice season (30-35°C), but gradually decreased in the course of the season (25°C by mid September).

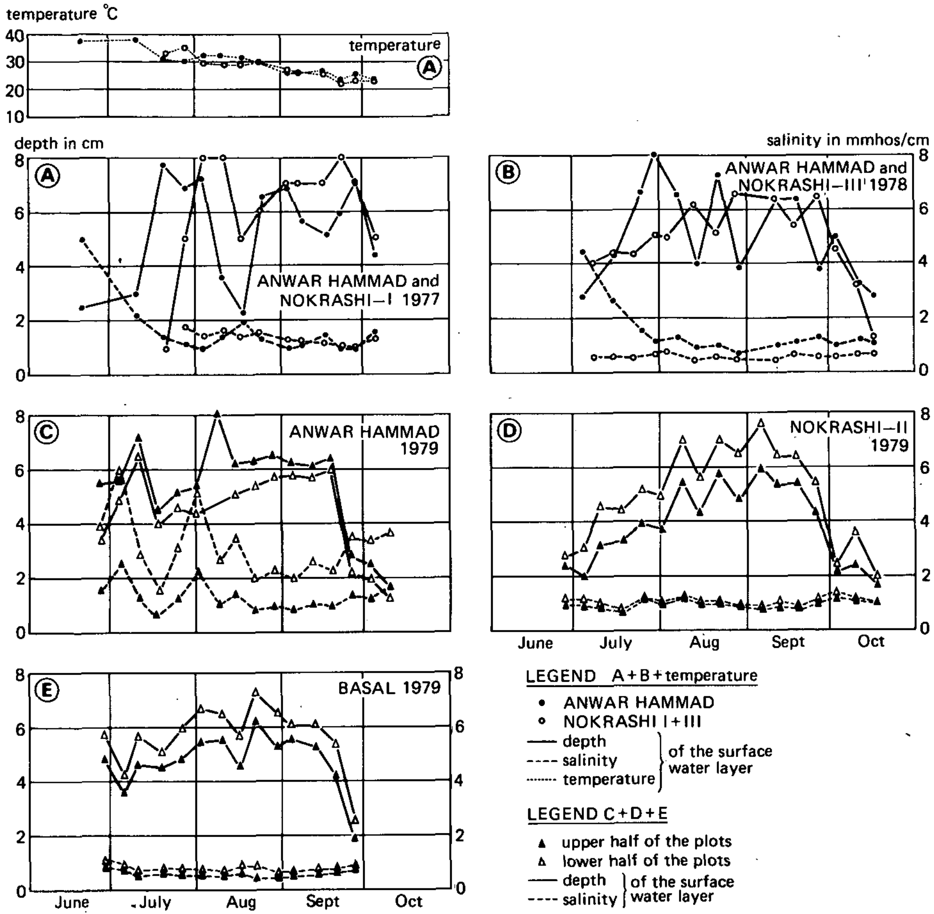


Figure 3.17 Average depth, salinity, and temperature of the surface water layer

3.5 Water and salt balance

The water and salt balance of the pilot areas were drawn up to investigate the effect of water management practices on the water and salt balances of tile-drained and non-tile-drained areas.

3.5.1 Water balance

The general expression of a water balance is: incoming water = outgoing water + change in storage. In irrigated rice cultivation, where it is common practice to keep the fields flooded, a surface water reservoir and a saturated soil reservoir may be distinguished. At the beginning of the rice growing season the soil has been dried out by the preceding winter crop. The soil becomes saturated after the first irrigation and will remain so until the end of the season as long as the fields are kept flooded. No rainfall is registered during the rice cropping season. The head difference between the ponded water level on the rice fields and the watertable level in adjacent lands will cause lateral groundwater movement. Moreover, readings of piezometric levels (Section 3.3) indicated a vertical natural drainage flow.

The 'overall' water inflow and outflow in irrigated fields, can therefore be described by the following equation:

$$I = D_{sr} + D_{ss} + D_n + ET + \Delta W_{sl} + \Delta W_s,$$

where

I = irrigation water inflow
D_{sr} = surface drainage water outflow
D_{ss} = subsurface drainage outflow
D_n = natural drainage losses
ET = evapotranspiration
ΔW_{sl} = change in storage of the surface water reservoir
ΔW_s = change in storage of the soil water reservoir

Each term of the water balance represents a volume of water per unit of time. The terms of water balance are expressed in units of discharge per area (mm) per considered time period. The change in storage is the difference in quantities of water between the beginning and the end of the time period.

The water inflow and outflow in rice fields is illustrated in Figure 3.18 (non-tile-drained rice fields) and Figure 3.19 (tile-drained rice fields).

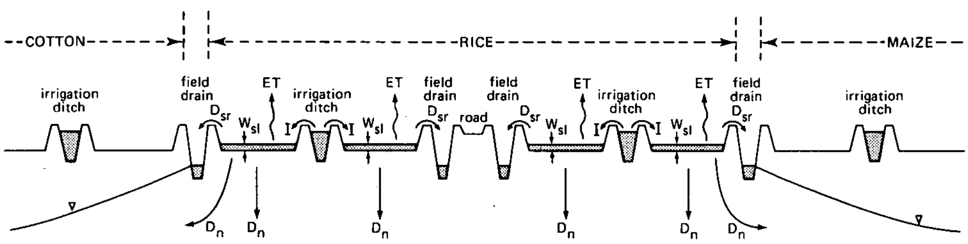


Figure 3.18 Water balance components of non-tile-drained rice fields

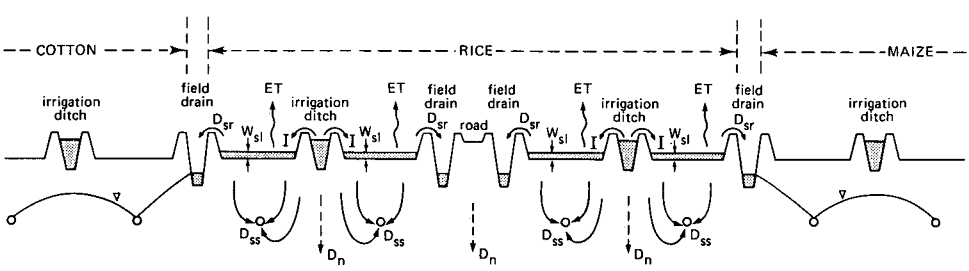


Figure 3.19 Water balance components of tile-drained rice fields

At the beginning and end of the rice growing season there is no storage in the surface water reservoir. If we take a growing season as the time period, the term ΔW_{sl} can be eliminated. For rice fields without a subsurface drainage system, the subsurface drainage water outflow component (D_{ss}) of the drainage water balance can be cancelled.

The natural deep drainage (D_n) has been set at zero for tile-drained rice fields, assuming that it is very small compared to the drainage flow towards the subsurface drainage system. The natural drainage losses (D_n) in non-tile-drained areas were estimated at 0.5 mm/day, using the formula (UNDP/FAO, 1966):

$$D_n = (I \times EC_{ir})/EC_g,$$

where

I = irrigation water intake, in mm/day;
EC_{ir} = average salinity of the irrigation water, in mmhos/cm;
EC_g = average salinity of the groundwater, mmhos/cm.

The weekly water balances were assessed for all three pilot areas. The cumulative changes of the water balance components during the rice growing season are plotted in Figure 3.20. The summed seasonal values of the terms of the water balance are presented in Table 3.6.

Table 3.6 Water balance components (seasonal totals) of the rice areas

		I	D_{sr}		D_{ss}		D_n		ET		ΔW_s	
		mm	mm	%[1]	mm	%[1]	mm	%[1]	mm	%[1]	mm	%[1]
Anwar Hammad	1977	1350[2]	505	37			60	5	660	49	125	9
	1978	1500	575	38			70	5	750	50	105	7
	1979	1340	325	24			80	6	845	63	90	7
Nokrashi	1977	1260[2]	20	2	420	33			670	53	150	12
	1978	1270	255	20	130	10			750	59	135	11
	1979	1180	180	15	105	9			770	65	125	11
Basal	1979	1165	210	18			75	6	775	67	105	9

[1] percentage of the total amount of irrigation water
[2] excluding nursery period

The evapotranspiration of rice was calculated from monthly Penman averages at the nearby Damanhour Meteorological Station. Small differences in ET between the pilot areas are due to differences in the considered rice growing period for each area.

The amount of surface drainage water at the saline Anwar Hammad farm is twice that of the non-saline areas (Nokrashi and Basal). Approximately one third of the total irrigation application was discharged through the surface system. In the Nokrashi tile-drained area, surface drainage was very small when the subsurface drainage system was functioning properly. The saline, non-tile-drained Anwar Hammad farm required more irrigation water to refresh the surface water layer and keep salinity low.

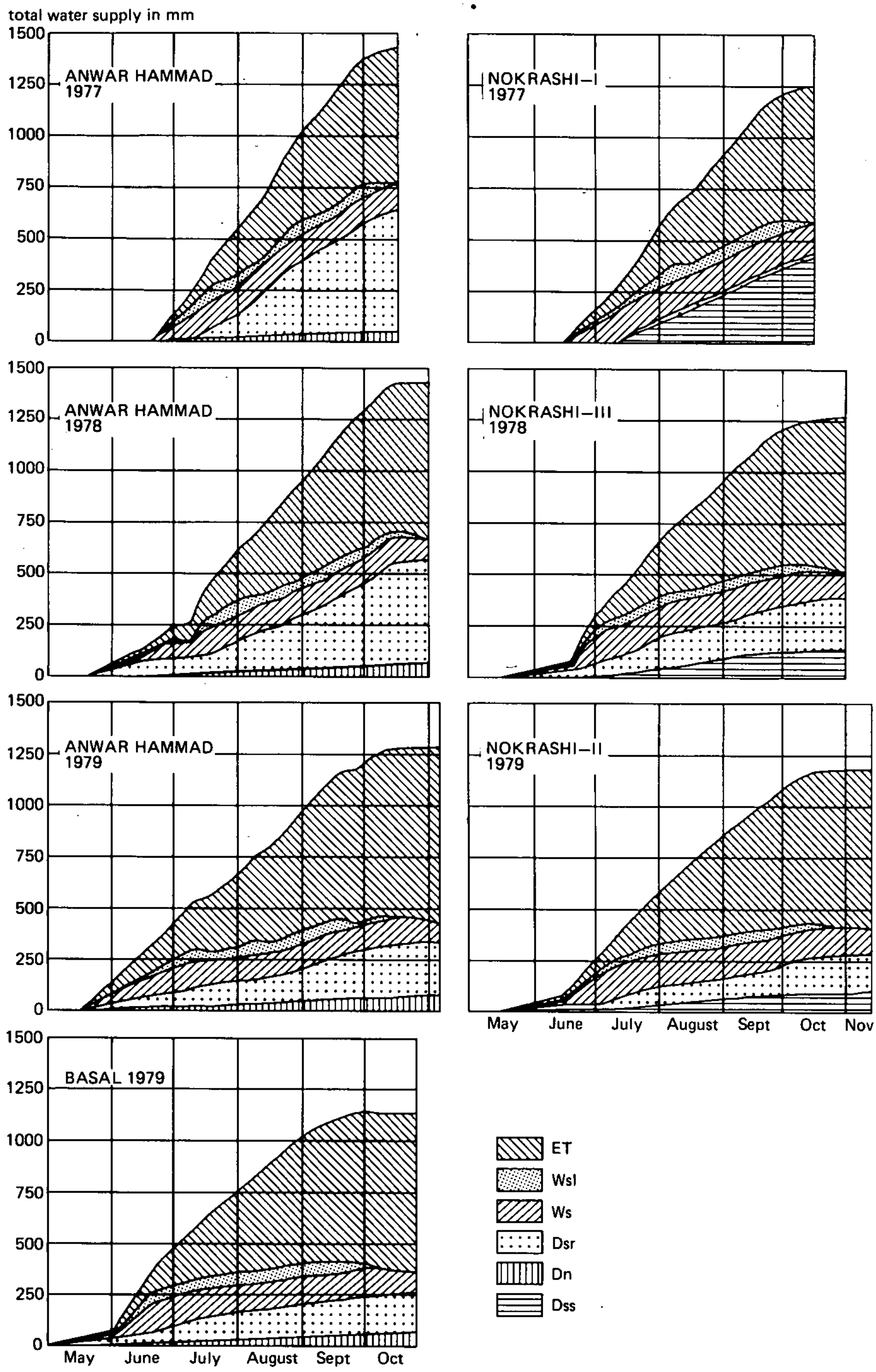


Figure 3.20 Water balances of the pilot areas

3.5.2 Salt balance

To assess a salt balance of the soil profile in a rice cropped area, the water quantities of the water balance must be multiplied by their salt concentrations. It is assumed that all salts are highly soluble and that they do not precipitate. The general equation for the salt balance of the soil profile of a drained area then reads:

$$\Delta Z = Z_{ir} - Z_{sr} - Z_n - Z_{ss},$$

where
ΔZ = change in salt content; a negative value stands for a decrease in salt content;
Z_{ir} = input of salts from irrigation;
Z_{sr} = output of salts from surface drainage;
Z_n = output of salts from natural drainage;
Z_{ss} = output of salts from subsurface drainage.

All the terms are expressed in tons of salt per hectare. For this, the EC-values of the water balance components are converted into ppm with the help of the formula $C = 640 \times EC$ (Richards 1954). EC in mmhos/cm and C = salt concentration in ppm.

The salt balance equation for a non-tile-drained area differs from that of a tile-drained area because the subsurface drainage component can be eliminated from the equation. The equation thus reads:

$$\Delta Z = Z_{ir} - Z_{sr} - Z_n$$

The salinity of several water balance components fluctuated sharply (Figure 3.21). This renders calculations of the increase of soil salinity rather imprecise when carried out for short periods of time. On the other hand, when taking longer periods and thus introducing more reliable volumetric figures, it becomes increasingly difficult to make a proper estimate of the weighted mean salinity of the involved components.

The data for the three pilot areas presented below are seasonal average values for the salinity of the water balance components. Table 3.7 presents the relevant data of the salt balance for the whole rice growing season.

Table 3.7 Salt balance components, in tons/ha over the layer 0-100 cm

Area		ΔZ	Z_{ir}	Z_{sr}	Z_n	Z_{ss}
Anwar Hammad farm	1977	−7.6	6.1	8.7	5.0	
	1978	−5.3	6.7	5.4	6.6	
	1979	−0.8	6.9	2.4	5.3	
Nokrashi area	1977	+1.8	8.0	0.2		6.0
	1978	+0.2	3.2	1.3		1.7
	1979	+2.8	5.9	1.1		2.0
Basal area	1979	−1.6	2.5	1.0	3.1	

The salt balance calculations of the non-tile-drained areas with high initial soil salinity levels show desalinization of the soil profile. A very modest increase is calculated

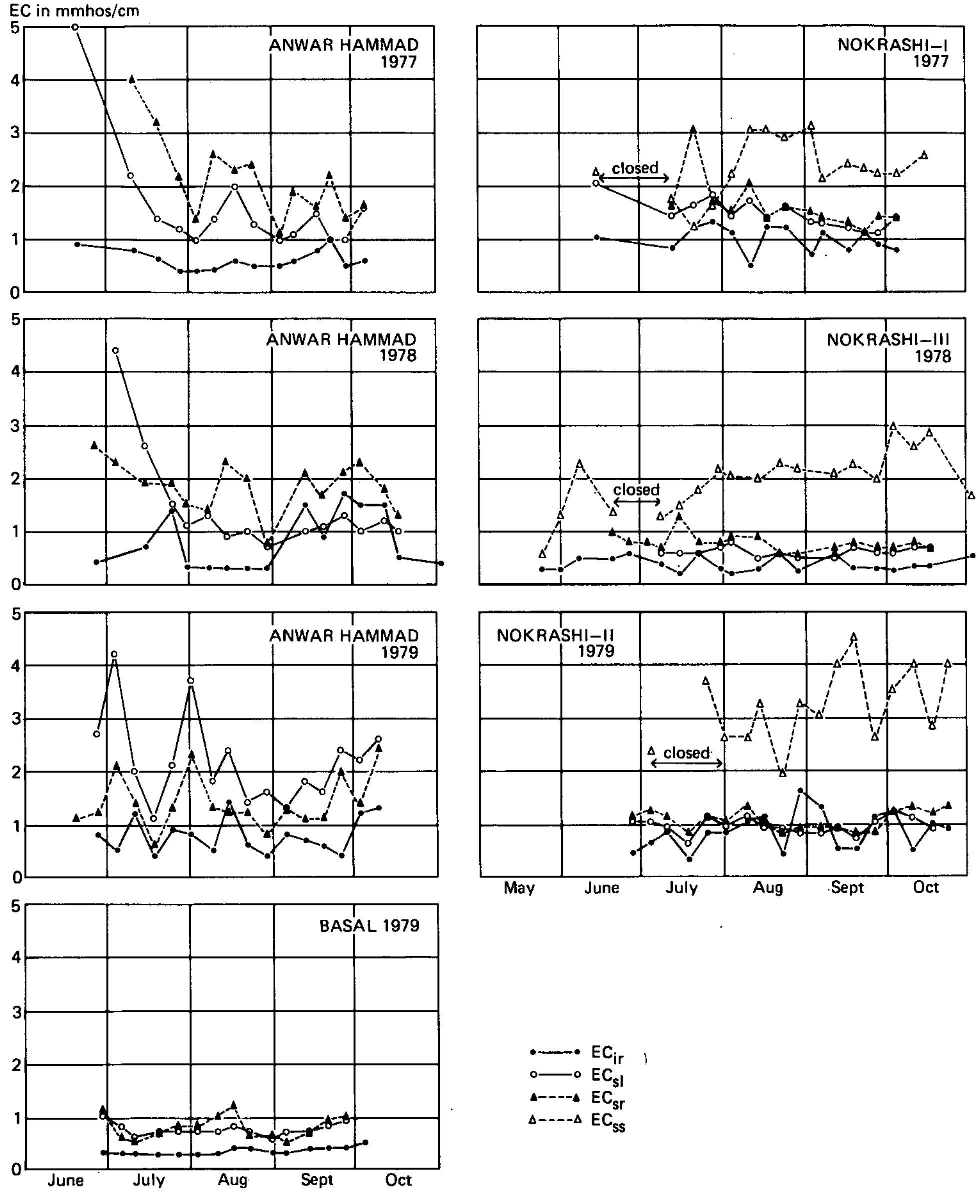


Figure 3.21 Salinity of the water balance components

in the Nokrashi area where soil salinity was very low at the beginning of the rice growing season.

The changes in salt content of the soil profile (0-100 cm) were also calculated from the results of the laboratory analysis of soil samples taken at the beginning and end of the rice season (Section 3.2). According to these calculations the desalinization was considerably more, and showed a modest desalinization, even for the Nokrashi area (Table 3.8). Apparently a considerable amount of salts covering the faces of the structural elements forming the 'walls' of the deeply penetrating cracks in the soil were flushed to soil layers below 1 m depth during the first inundation prior to land preparation, and thus did not appear in the soil samples taken to a depth of 1 m.

Table 3.8 Change in salt content (ΔZ) according to soil sample analysis, in tons/ha

Area	1977	1978	1979
Anwar Hammad farm	−22	−15	+13
Nokrashi area	− 1	− 2	−10
Basal area			− 6

The salt balance at the Anwar Hammad farm showed an almost negligible desalinization in 1979 (Table 3.7), whereas the soil sample analysis (Table 3.8) indicated an increase in soil salinity at the end of the rice season. The serious lack of irrigation water during certain periods before and after transplanting the rice, may have caused an upward movement of highly saline soil moisture at that time, instead of a slow but permanent downward natural drainage flow. In this case the natural drainage component, although small, is overestimated, which means that less salt than assumed is leached below a depth of 1 m. Reducing the natural drainage to half results in a resalinization of 2 tons/ha, according to the salt balance.

3.6 Some important physical factors influencing rice production

3.6.1 General

The combined effects of numerous independent and interdependent physical factors determine the yield. Soil salinity, water availability and water quality, and the depth and salinity of the surface water layer probably rank among the most important factors from the point of view of water management. Fertilizer rates and various agronomic measures, like date of sowing, age of seedlings, weeding, and pest- and disease control measures, are also important. It was, however, beyond the objectives and scope of this programme to assess their influence on rice production.

The team was primarily interested in the relation between rice yield (Y), and topsoil salinity (S_s), salinity of the surface water layer (S_w), and the depth of this water layer. These data were collected during the rice season at the plots of the crop cuttings. Complete sets of data for all three pilot areas were only available for the year 1979. The statistical analysis was therefore limited to data for 1979.

The objective of the statistical analysis was mainly to answer the following questions:
- Do soil salinity, and salinity and depth of the surface water layer hamper the rice production in the pilot areas? If so, to what extent?
- What could the production increase be if these factors are controllable?

3.6.2 Statistical methods used

The statistical analysis was restricted to only two-variable linear regressions with yield (Y) as the dependent variable. Breakpoints were introduced for the independent variables (the growth factors) where appropriate, after which linear regressions were made separately to the left and right of the breakpoint. The breakpoint thus represents a critical or threshold value, separating the growth factor into parts with a significant influence on the yield and parts without any influence. Thus, a non-linear production function is linearized by a broken line. The residual yield variations (RY), remaining after the broken line regression upon one of the growth factors (for example S_s or S_w), were subjected to a similar regression for the other variable (S_w or S_s). If the two growth factors showed a considerable correlation, then the second growth factor was reduced (to RS_w or RS_s respectively) in order to eliminate that part of the variation that had already been accounted for by the regression for the first independent variable.

The advantage of this method is that it allows confidence statements to be made with the methods known from the two-variable linear regression theory. Further, the multi-dimensional function can be presented by two-dimensional illustrations, and the correlation between growth factors can be directly accounted for. Reference is made to Dendy (1976), Ezekiel and Fox (1959), and Snedecor and Cochran (1967). The following set of equations is obtained:

$$
\begin{array}{lll}
EY & = a(S_1 - MS_1) + MY & (S_1 < BS_1 \text{ or } S_1 > BS_1) \\
ES_2 & = c(S_1 - MS_{1t}) + MS_{2t} & (S_1 < BS_1 \text{ and } S_1 > BS_1) \\
RS_2 & = S_2 - c(S_1 - MS_{1t}) & (\text{if } c = 0, RS_2 = S_2) \\
RY & = Y - EY & \\
ERY & = b(RS_2 - MRS_2) + MRY & (RS_2 < BRS_2 \text{ or } RS_2 > BRS_2) \\
EFY & = EY + ERY & \\
 & = a(S_1 - MS_1) + b(RS_2 - MRS_2) + MY + MRY & \\
 & = a^* \times S_1 + b^* \times S_2 + p & \\
 & \quad (\text{if } c = 0\text{: } a^* = a, b^* = b) & (S_1 < BS_1 \text{ and } S_2 < BS_2 \\
 & & \text{or } S_1 > BS_1 \text{ and } S_2 < BS_2 \\
 & & \text{or } S_1 < BS_1 \text{ and } S_2 > BS_2 \\
 & & \text{or } S_1 > BS_1 \text{ and } S_2 > BS_2)
\end{array}
$$

where

S_1 = 1st growth factor (S_s or S_w)
S_2 = 2nd growth factor (S_w or S_s)
BS_1 = breakpoint of S_1
BS_2 = breakpoint of S_2
BRS_2 = breakpoint of RS_2
EY = expected value of Y according to the regression of Y upon S_1 divided into two parts: left and right of BS_1
MS_1 = mean value of S_1 either left or right of BS_1
MY = mean value of Y either left or right of BS_1
ES_2 = expected value of S_2 according to the regression of S_2 upon S_1 using all data

MS_{1t} = mean value of S_1 using all data
MS_{2t} = mean value of S_2 using all data
RS_2 = reduced value of S_2 eliminating its variation already explained by S_1
ERY = expected value of RY = Y – EY according to the regression of RY upon RS_2 divided into two parts: left and right of BRS_2
EFY = expected final value of Y
MRS_2 = mean value of RS_2 either left or right of BRS_2
MRY = mean value of RY = Y – EY
a,b,c = regression coefficients
a*,b* = production coefficients
p = production constant

3.6.3 Yield and topsoil salinity

Figure 3.22 presents the grain yields (Y) in relation to the topsoil salinity (S_s).

At the Anwar Hammad farm, the S_s values go up to 8 mmhos/cm. It is noticeable that the maximum yields, represented by the upper envelope curve, tend to decrease sharply with increasing topsoil salinity in the range of $S_s = 3$ to 8 mmhos/cm.
The broken line regression yields:

$EY = MY = 3.4$ ton/ha ($S_s < 3$ mmhos/cm, n = 17)
$EY = 2.8 - 0.80(S_s - 4.5)$ ton/ha ($S_s > 3$ mmhos/cm, n = 31)
n = number of observations

The coefficient of explanation R^2 is 0.25. The 90% confidence limits of the regression coefficient $a = -0.80$ (for $S_s > 3$) are –0.36 and –1.25. Hence the value of a is not accurate but it is significant. Therefore $S_s = 3$ mmhos/cm represents a critical value of topsoil salinity below which the yields are little affected by S_s, but above which the yields decrease with increasing S_s.

The two regression lines do not intersect at $S_s = 3.0$, but at $S_s = 3.7$ mmhos/cm. This is an indication that the breakpoint cannot be determined precisely. Perhaps it is somewhat higher. The reason for the limited accuracy is the large unexplained part of the variation of the data due to the other unknown growth factors. The order of magnitude of the breakpoint, however, is quite clear.

Nijland and El Guindy (1984) found a breakpoint of 3.5 to 4 mmhos/cm for rice in the Nile Delta; the average production level below the breakpoint in the investigated areas, however, was higher than at the Anwar Hammad farm. FAO's guidelines indicate yield decrement to be expected at EC_e values > 3 mmhos/cm (Ayers and Westcot 1985).

The yield expectation at the Anwar Hammad farm for $S_s < 3$ mmhos/cm is still considerably less than in the other regions, and this is only partly explained by topsoil salinity. From Figure 3.22, it can be seen that yields in the lower parts of the fields are considerably less than in the upper parts. Most lower parts have topsoil salinities $S_s > 3$ mmhos/cm, whereas most upper parts have $S_s < 3$ mmhos/cm.

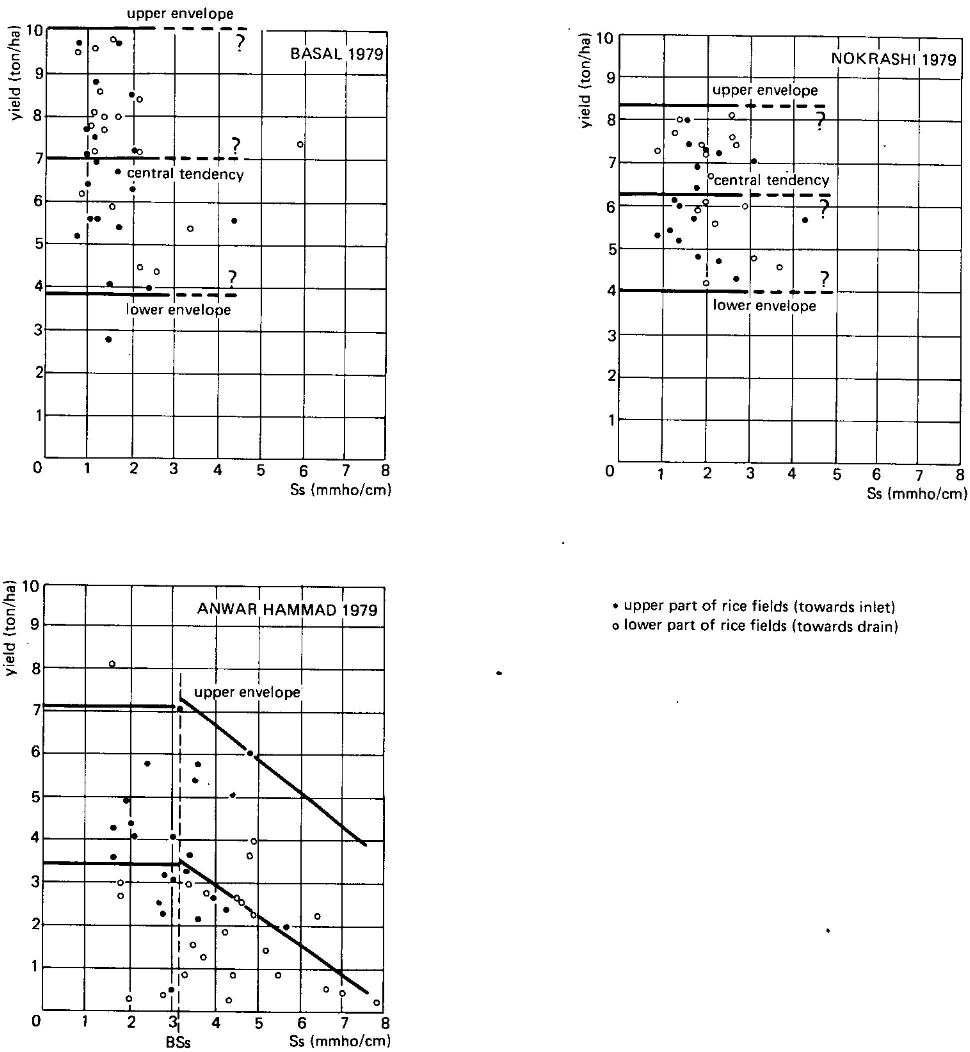


Figure 3.22 Relationship between yield and topsoil salinity

There are few S_s values higher than 3 mmhos/cm in the Basal area. There is no trend of yield decrease with increasing S_s values. A topsoil salinity of 3 mmhos/cm is apparently safe, and is rarely exceeded. In the Nokrashi area the same is true. Hence the salinity of the topsoil does not explain the somewhat lower average yield in Nokrashi compared with Basal.

3.6.4 Yield and salinity of the surface water layer.

Figure 3.23 presents the grain yield (Y) in relation to the salinity of the surface water

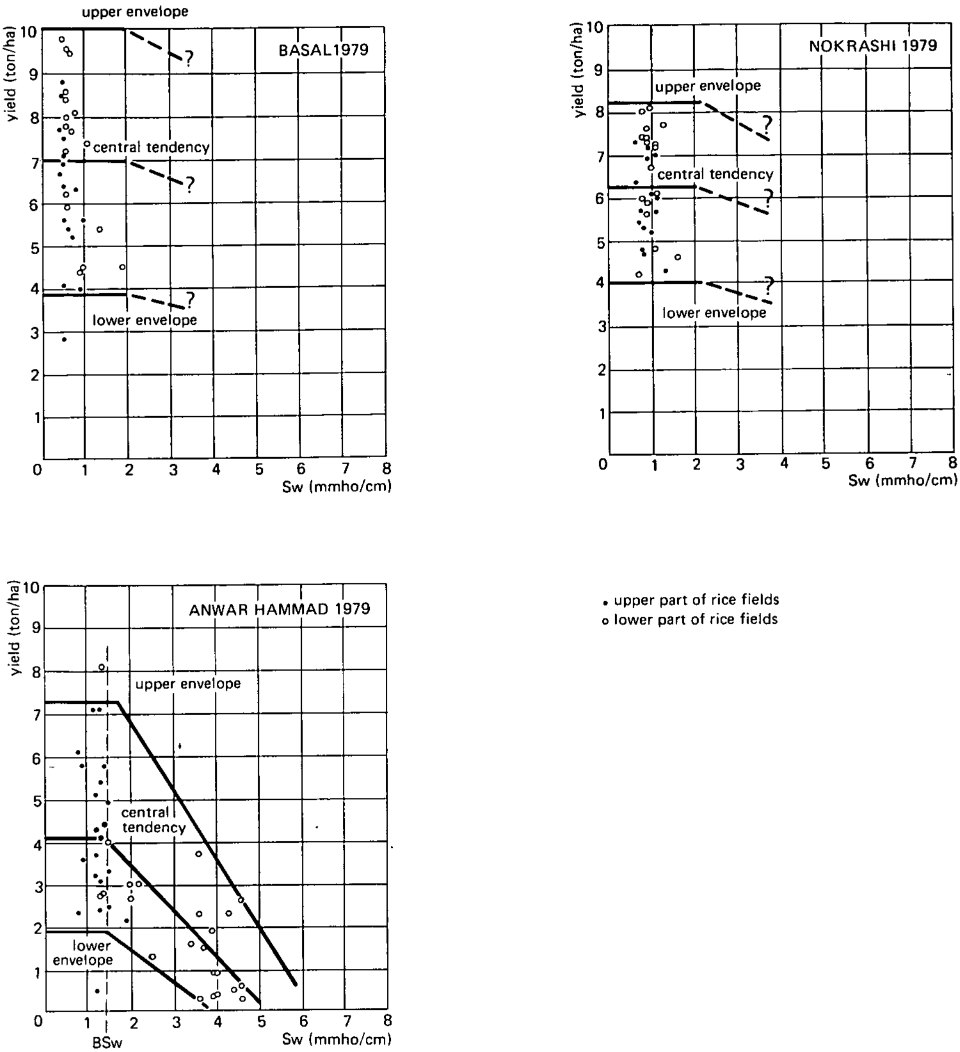


Figure 3.23 Relationship between yield and surface water salinity

layer in the rice fields (S_w). As with S_s, the yields in Basal and Nokrashi are not affected by S_w, and the maximum observed values of 2 mmhos/cm appear to be safe. The (Y, S_w) relation in the Anwar Hammad region shows the same trends as the (Y, S_s) relation. The broken line analysis yields:

EY = MY = 4.1 ton/ha	(S_w < 1.3 mmhos/cm, n = 10)
EY = 2.7-1.0(S_w − 2.6) ton/ha	(S_w > 1.3 mmhos/cm, n = 38)

The 90% confidence limits of the regression coefficient a = −1.0, are −0.70 and −1.3. The exact value of the coefficient, a, can vary considerably, however it remains significant. The two regression lines intersect at $S_w = 1.2$ mmhos/cm, which approximates to the breakpoint $BS_w = 1.3$ mmhos/cm. The total coefficient of explanation $R^2 = 0.44$ is significantly higher than for the (Y, S_s) regression. Like the S_s values, the S_w values only partly explain lower yields at the Anwar Hammad farm compared with the other two regions. There must also be other factors than topsoil and surface water salinity responsible for the lower average yields at the farm.

3.6.5 Yield and depth of the surface water layer

Figure 3.24 shows the relationship between grain yield of rice (Y) and the seasonal

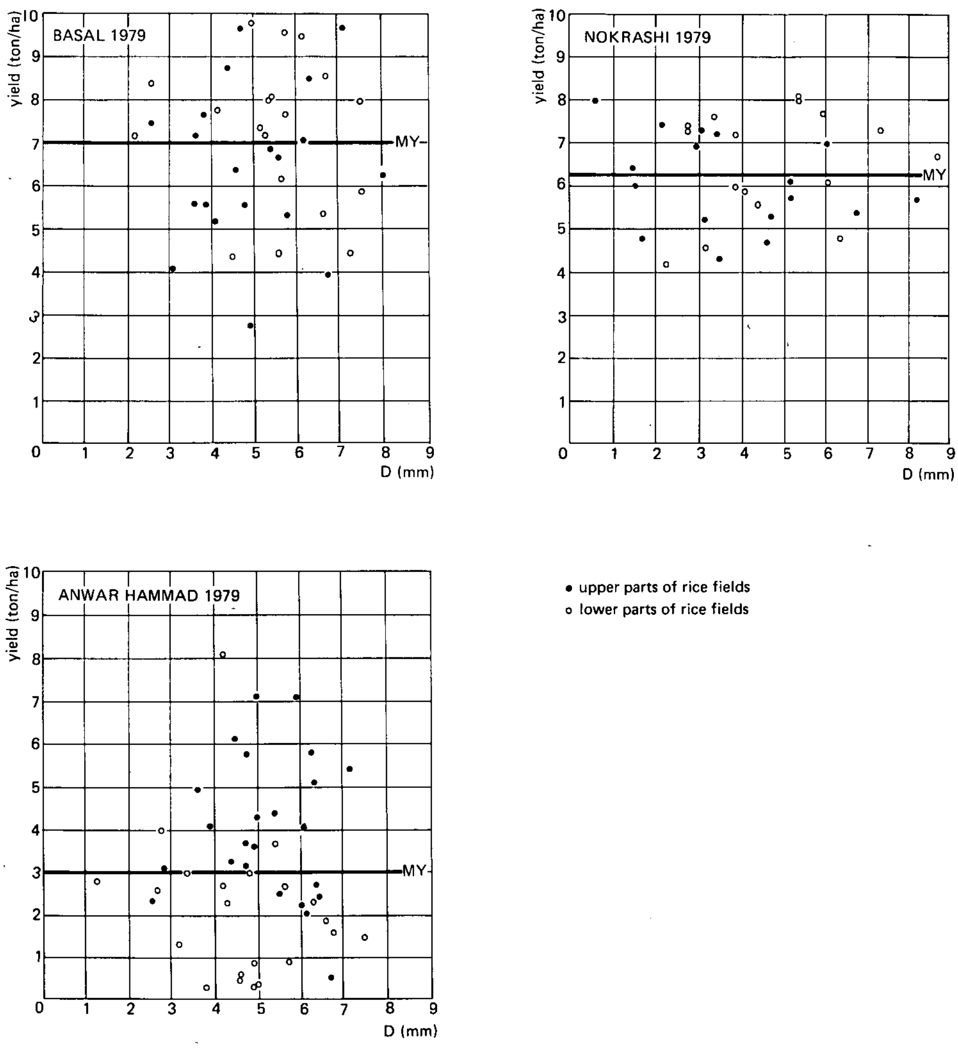


Figure 3.24 Relationship between yield and surface water depth

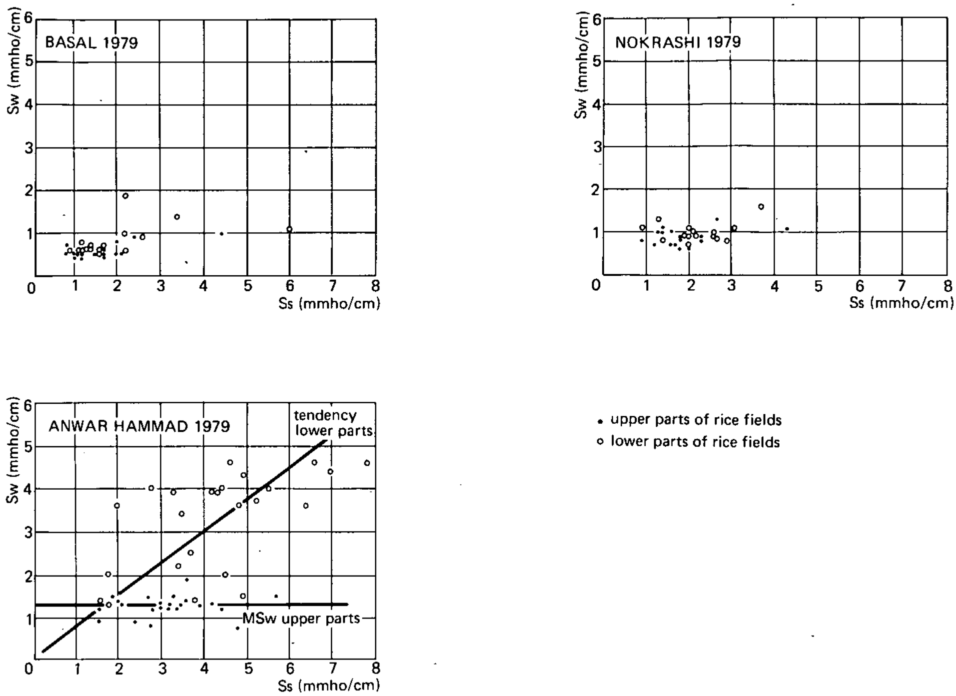


Figure 3.25 Relationship between S_w and S_s

average depth of the surface water (D). Although D varies from 1 to 9 cm, it has no significant effect on the yield. It appears that it is not necessary to maintain a strict depth of the surface water layer, in the range of 3 to 7 cm. De Wolf et al. found that the optimum water level ranges from 6 to 10 cm for lowland rice cultivation.

From experiments conducted in the central part of the Nile Delta near Sakha, the Egyptian Water Requirement and Irrigation Systems Research Institute (WRISRI) derived an optimum yield at a depth of 7 cm (DRI, 1986b).

3.6.6 Relationship between topsoil salinity and surface water salinity

Figure 3.25 plots S_w against S_s. For the Anwar Hammad farm the correlation coefficient r is 0.60. S_w and S_s appear to be rather interdependent but only in the lower part of the fields. However, S_w and S_s are not interdependent in the fields in the Nokrashi and Basal areas.

3.6.7 The relationship between Y, S_w, and S_s at the Anwar Hammad farm

The regression of Y upon S_w was seen to be more effective than Y upon S_s (Table 3.9). The introduction of (reduced) S_s after the (Y, S_w) regression does not lead to further reduction of the residuals. Hence the production function given in Section

3.6.5 cannot be further improved. The introduction of (reduced) S_w after the (Y, S_s) regression can reduce the sum of squared residuals from 138 to a minimum of 96.

The resulting three-dimensional production function is therefore not significantly more effective than the two-dimensional (Y, S_w) function.

Table 3.9 Regression equations for the Anwar Hammad farm

		$\Sigma(RY)^2$
1) Regression of Y upon S_s		
all data		182
$S_s < 3$ mmhos/cm	EY = MY = 3.4 ton/ha	
$S_s > 3$ mmhos/cm	EY = $2.8 - 0.8\,(S_s - 4.5)$ ton/ha	138
2) Regression of Y upon S_w		
$S_w < 1.3$ mmhos/cm	EY = MY = 4.1 ton/ha	
$S_w > 1.3$ mmhos/cm	EY = $2.7 - 1.0\,(S_w - 2.6)$ ton/ha	98
3) Introduction of (reduced) S_s after (Y, S_w) regression		94
4) Introduction of (reduced) S_w after (Y, S_s) regression		96

3.6.8 Estimated benefits of salt control

The salt contents of the rice plots in the Basal and Nokrashi areas are presently at safe levels. Additional measures for salt control for rice cultivation are not required as they would not boost production.

At the Anwar Hammad farm the production increment (Y_i) can only be estimated by assuming that the salinity of the surface water layer is controlled to be less than or equal to the safe level of $BS_w = 1.3$ mmhos/cm in the following manner:

$$Y_i = \Sigma a(BS_w - S_w)/n$$

With $a = -1.0$ for data with $S_w > BS_w$ and $a = 0$ for $S_w < BS_w$ the average production increase will be 1.0 ton/ha, amounting to 33% of the present average yield of 3.0 ton/ha. The 90% confidence interval of the increase in yield ranges from 23 to 43%.

3.7 Conclusions

The main conclusions drawn from the results of the investigation are summarized in the following sections. An alternative to the present layout of the subsurface drainage system is given.

3.7.1 Rice yields

The average rice yields at the saline Anwar Hammad farm were considerably lower than in the non-saline Nokrashi and Basal regions (3.6 ton/ha versus 6.5 and 7.3 ton/ha respectively). This difference in yields could partly be explained by the soil salinity and the salinity of the surface water layer. Salt control measures alone will not completely eliminate this difference, although a production increase of 33% could result.

Nijland (1983) found 25% higher rice yields in subsurface drained (non-saline) areas compared with yields in the non-subsurface drained (saline) areas in the Nile Delta. The installation of a subsurface drainage system in saline areas like the Anwar Hammad farm may contribute in great measure to an increase of the production of non-rice crops. To attain the production levels of the Basal and Nokrashi regions other measures, e.g. agronomic, may be necessary.

The salt contents of the rice plots in the Basal and Nokrashi areas are presently at safe levels for the rice production. Additional measures for salt control in the Basal area (subsurface drainage system) would not boost rice production, but could increase the production of more salt sensitive crops during the periods when rice is not cultivated.

3.7.2 Levelling

Careful levelling of the rice fields is necessary, especially in low productive (saline) areas, so as to obtain a better control of the depth and salinity of the surface water layer. In non-subsurface drained areas, care should be taken to open the borders of the fields at several widely separated points, thus ensuring complete drainage of the old surface water and reduce the risk of high salinity levels in the lower parts of each plot.

3.7.3 Surface water layer

The salinity of the surface water layer affects the rice yields. Rice yields decline sharply at an average EC > 1.3 mmhos/cm. Water management in saline areas should aim at maintaining a low salinity level in the surface water layer. Frequent refreshment of the surface water should be carried out, especially when the available irrigation water is of low quality.

3.7.4 Soil salinity

An approximate threshold value for topsoil salinity of 3 to 4 mmhos/cm could be assessed at the saline Anwar Hammad farm. Flushing the plots before transplanting rice could greatly reduce a high initial topsoil salinity. This practice, however, requires considerable amounts of water at times when irrigation water is in short supply.

During the rice cropping season, the decrease in topsoil salinity of the non-subsurface drained rice soils is quickly halted under the following (rotating) berseem and/or cotton crop. The salt balance in the subsurface drained area remains approximately at the same low level, despite the temporary blocking of the subsurface drainage system.

3.7.5 Irrigation water applications

The average total irrigation water application during the rice growing season was 15% higher at the Anwar Hammad farm than in the tile-drained Nokrashi area. Flushing of the saline surface water layer at the beginning of the season required more irrigation water at the Anwar Hammad farm. The irrigation water requirement of rice in the Nokrashi area is directly related to the degree the subsurface drainage system is blocked. This is carried out by farmers in June and July, when the rice plots suffer from lack of water. Water shortage during these months occurs throughout the Delta (Ley and Tinsley, 1983; Nijland, 1983).

Peak demand in irrigation water occurs during the short transplanting period, which in most areas is less than 4 weeks. An ample supply of good quality irrigation water in the Basal area did not, however, lead to high irrigation water applications.

The quality of the irrigation water was much better in the Basal area compared with the two other pilot areas (EC = 0.35 mmhos/cm versus EC = 0.8 mmhos/cm).

3.7.6 Drainage system

The size of the original open field drains may be reduced after the installation of a subsurface drainage system as they will have no further function in the control of the watertable. A shallow open drain serving all plots at the low-lying side, will have to remain in place, to drain tail irrigation water of other crops rotating with rice, and also allow for some surface drainage practice during rice growing, e.g. discharge of the surface water layer before fertilizer application and temperature control. If these provisions are not made, the farmers will be tempted to remove undesired amounts of surface water into the nearby manholes of the subsurface drainage system, and thus endanger its proper function (Figure 3.26).

Farmers in the subsurface drained Nokrashi area felt compelled to reduce water losses and frequently blocked collectors in a rather primitive way. This resulted in insufficient drainage of non-rice crops at the upstream collector ends. The inevitable conclusion is that no proper water management is possible as long as fields under rice and other crops are served by one and the same indivisible pipe drainage system. Either the rice, the other crops, or both will suffer from poor water management.

An effective solution to the problem would be the installation of a practical and reliable closing device at each lateral outflow of the drainage system. It is obvious, however, that such a solution would not be very practical. Apart from the high costs, it would make the entire drainage system extremely vulnerable and would lead to prohibitive operation and maintenance costs.

Rice and other crops are therefore preferably served by drainage units that can be operated separately and independently. Drainage units serving rice should be controllable, whilst units serving areas with other crops could drain freely.

The present system of crop consolidation, where summer crops are concentrated into fairly large blocks, suggests a most practical solution (Section 2.1). Modifying the layout of the drainage system so that subcollectors will also serve areas with a 'one-crop block' in the consolidated system, would make it possible to control the outflow of these units separately. This concept, originally formulated by Cavelaars

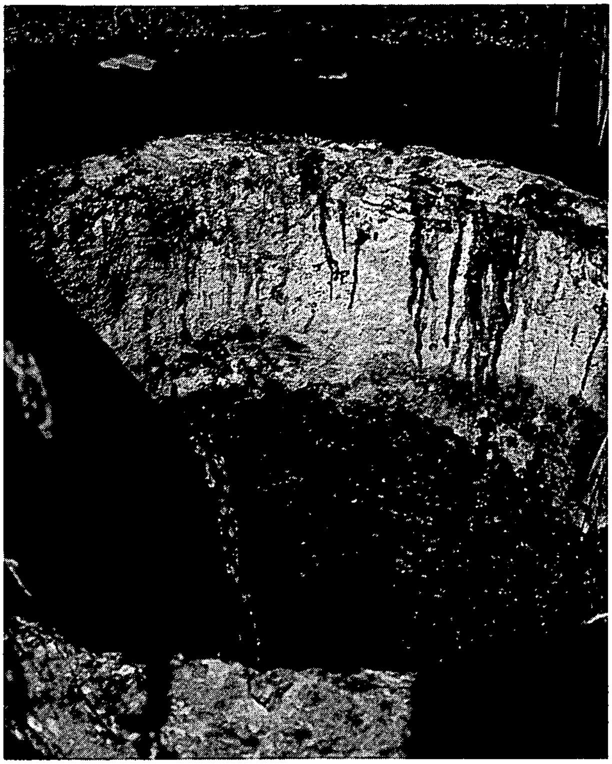


Figure 3.26 Manhole used for surface drainage

(VBB/ILACO, 1973; Cavelaars, 1978), is illustrated in Figures 3.27a and 3.27b.

The existing 'conventional' layout of the drainage system in the greater Nokrashi area, of which the investigated Nokrashi I, II, and III areas form a part, is shown in Figure 3.27a. The crop consolidated areas are also indicated. The collectors serve several cropping units. Applying the concept of a 'modified' layout to this area would have resulted in the layout presented in Figure 3.27b. Each cropping unit is now served by a subcollector ending in a manhole, where the drainage outflow of the unit can be controlled. This ensures continued proper drainage conditions for maize and cotton crops, growing alongside rice within the same area served by one main subsurface drainage collector.

For example, the Nokrashi areas III, VIII, and XII are cultivated with rice, whilst the other units contain cotton and maize. The drainage outflow of the rice growing units can be regulated by closing the subcollectors of these units in manhole No's 3 and 8. This can be achieved without interfering with the discharge of the upstream units.

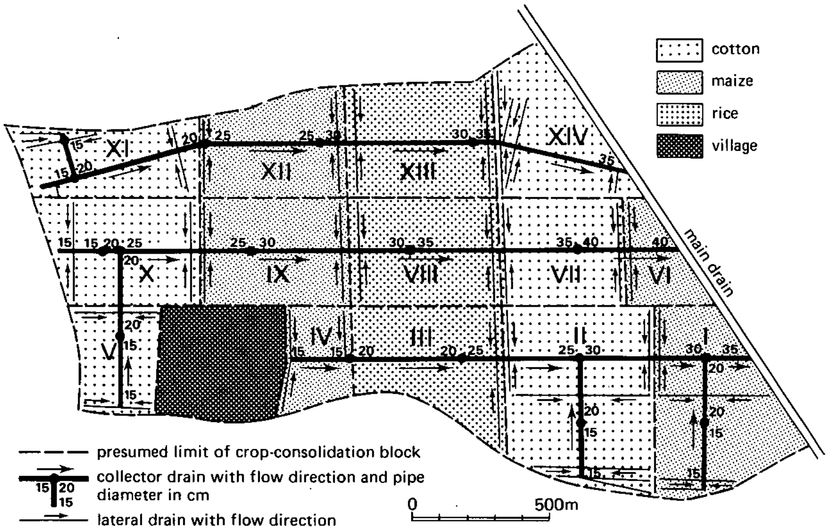


Figure 3.27a Conventional layout of the subsurface drainage system in the Nokrashi area

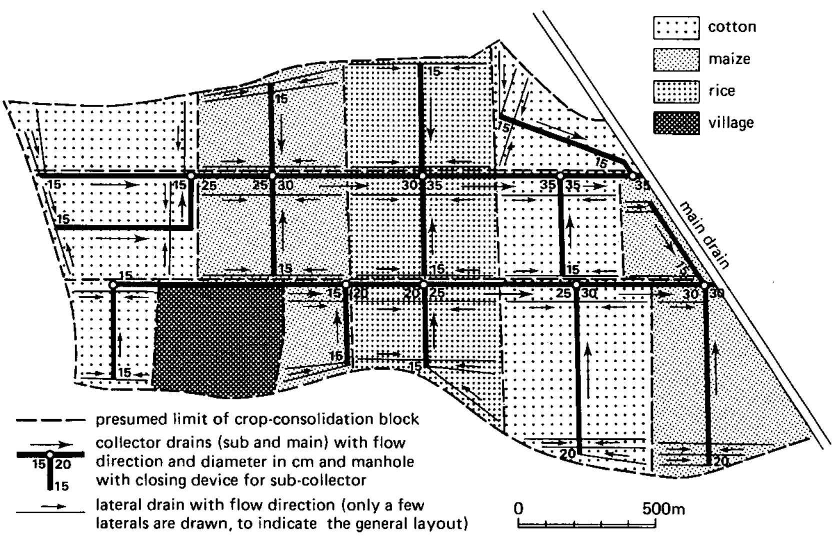


Figure 3.27b Possible modified layout with subcollectors to suit water management of rice fields

4 Modifying the design of subsurface drainage systems in rice growing areas

4.1 General

One of the findings of the investigations was that modification of the conventional layout of the subsurface drainage system would be necessary to meet the water management requirement in areas where rice rotates with other summer crops. The impact of a modified layout on the design of the drainage system will be discussed in the following sections. The ensuing guidelines for the design of subsurface drainage systems in rice growing areas have been used to formulate the concept of the modified layout for a sizeable prototype area in the eastern Delta, the Mahmudiya I area. The main objective was to test the practical and financial consequences of the modified system and its operation.

4.2 Design of drainage systems in rice growing areas

4.2.1 Technical design criteria and specifications

The modified layout of the subsurface drainage system implies that each subcollector serves an area coinciding with a cropping unit of the crop consolidation system. The subcollectors meet the main collector at a manhole, and closing devices should be installed to control the drainage unit outflow.

The design criteria for this modified layout can be the same as those applied for other crops. In the conventional design, a higher drainage duty for areas with rice is currently applied to calculate the collector pipe diameters (4 mm/day versus 2 mm/day for non-rice crops). The results of the investigations clearly indicate that high drain discharges are undesirable, and consequently the farmers block the subsurface drainage system. Even on the rare occasions that rapid drainage is desired, e.g. at the end of the rice season, this can still be achieved if the hydraulic capacity of the pipes is attuned to non-rice crops only. Temporary overpressure in the pipe is not a problem. Therefore drainage duties for the hydraulic design of laterals and collectors should be the same as for non-rice areas i.e. 2 mm/day.

The lower design discharge of the modified system will imply a reduction in size of pipes as compared to the current design norms, and thus lead to cost savings. This will, however, be partly offset by extra costs due to the increased total length of subcollector pipes compared with the conventional layout (Section 4.3.3). Other design features, e.g. spacing and depth of laterals (Section 2.2), will not differ from those in non-rice areas.

4.2.2 Delimitation of the subcollector units

The crucial element in designing the modified layout is the delimitation of the subcollector units. The areas drained by a subcollector unit should coincide with the prevailing crop consolidation blocks as far as possible. Information on the latter will have to be obtained from the agency responsible for the crop consolidation scheme, hereafter referred to as 'Agriculture'[1]). The subcollector units should be of reasonable size. Very small cropping units should be consolidated in large units. To keep the length of the subcollectors within practical limits, the minimum size of the drainage unit should be set at approximately 6 ha.

4.2.3 Design procedure

Compared with the current design procedure, only a few extra steps should be taken. To prepare the layout of the modified drainage system, the design engineer should have all data readily available on cropping units of the crop consolidation system. This relevant information in the form of good quality maps at a appropriate scale (1:10,000), are to be provided by or collected from 'Agriculture'.

A preliminary layout is prepared according to the technical criteria and specifications mentioned above. After field checks and discussions with 'Agriculture', the layout can be finalized. Copies of it are sent to 'Agriculture' who may use it to make minor modifications to cropping units wherever necessary and desirable, to increase the efficiency of the modified system.

4.3 Application of the modified layout to the Mahmudiya area

4.3.1 General

A design for the subsurface drainage system for the Mahmudiya I area was made according to the above guidelines. The Mahmudiya I area covers approximately 1925 ha, and lies in the eastern Delta near the town of Zagazig (Figure 4.1). The net cropped area, consisting mainly of heavy clay soils, covers approximately 1700 ha. The area represents average conditions of the crop consolidated areas in the Nile Delta. The Mashtul pilot area (108 ha), located within Mahmudiya I area, was constructed in 1980 according to the modified design concept. The construction of the drainage works in the Mahmudiya I area was completed in 1982. A monitoring programme was conducted to study the effects of the modified system and its practical operation. Simultaneously, the functioning of the subsurface drainage system with a conventional layout was monitored in a comparable neighbouring area, i.e. Mahmudiya II.

4.3.2 Layout

The modified layout of the subsurface drainage system in the Mahmudiya I area is

[1]) The terms 'Agriculture' and 'Irrigation' may stand for the Ministry at National level, for the concerning sector at provincial level, or for officials at district or village level.

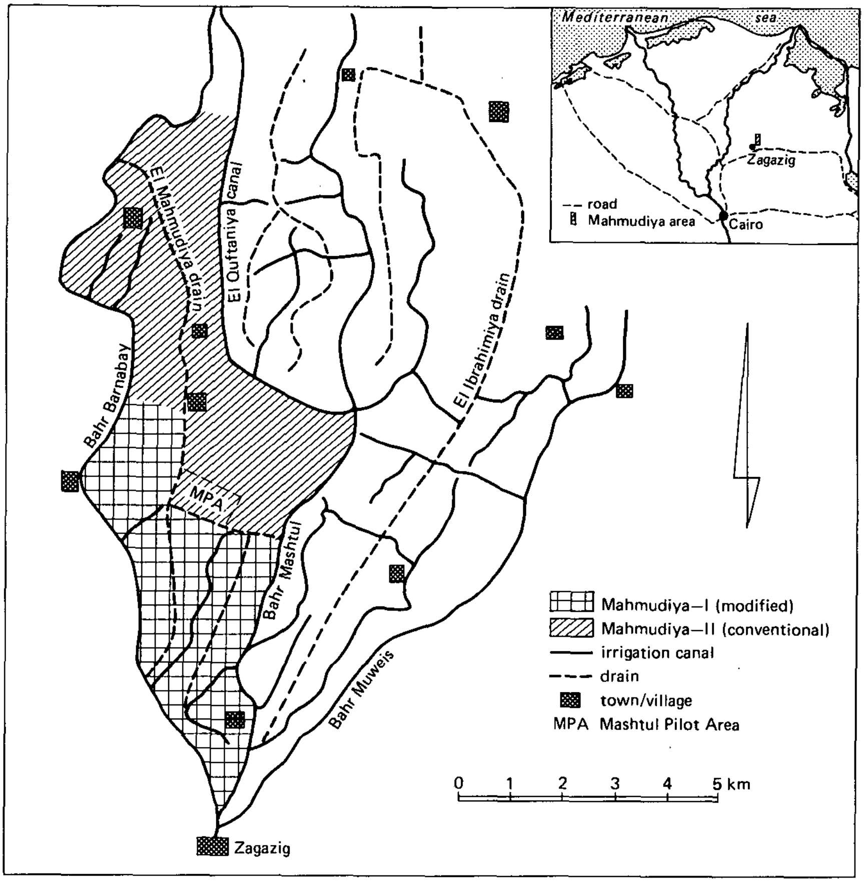


Figure 4.1 Location of the Mahmudiya area

shown in Figure 4.2a. The crop consolidation plans for three successive years were used to prepare this layout. The subcollector units could be adapted to the existing cropping units for 95% of the area. Near villages some small cropping units had to be grouped to one drainage unit. A complete match between subcollector units and the prevailing cropping units appeared possible, but is not strictly necessary. This was, however, left to 'Agriculture', who could easily make some minor modifications to the cropping units.

4.3.3 Costs

The total construction costs, including materials (drainpipes, manholes, etc.) of the modified drainage system have been compared with the construction costs of the conventional system for the same area. The layout of the conventional system is shown in Figure 4.2b. The list of quantities and construction costs for both systems is presented in Figure 4.3.

In a modified system the total length of the smallest collector pipes (diameter 15 cm) is much greater than in a conventional system, but there are fewer of the larger, more expensive sizes (diameter 20 to 50 cm). This is a direct result of the larger number of subcollectors required in the modified system, and the smaller drainage rate for the hydraulic design. The final result of the cost comparison favours the modified system, the costs of the conventional system being 3% higher.

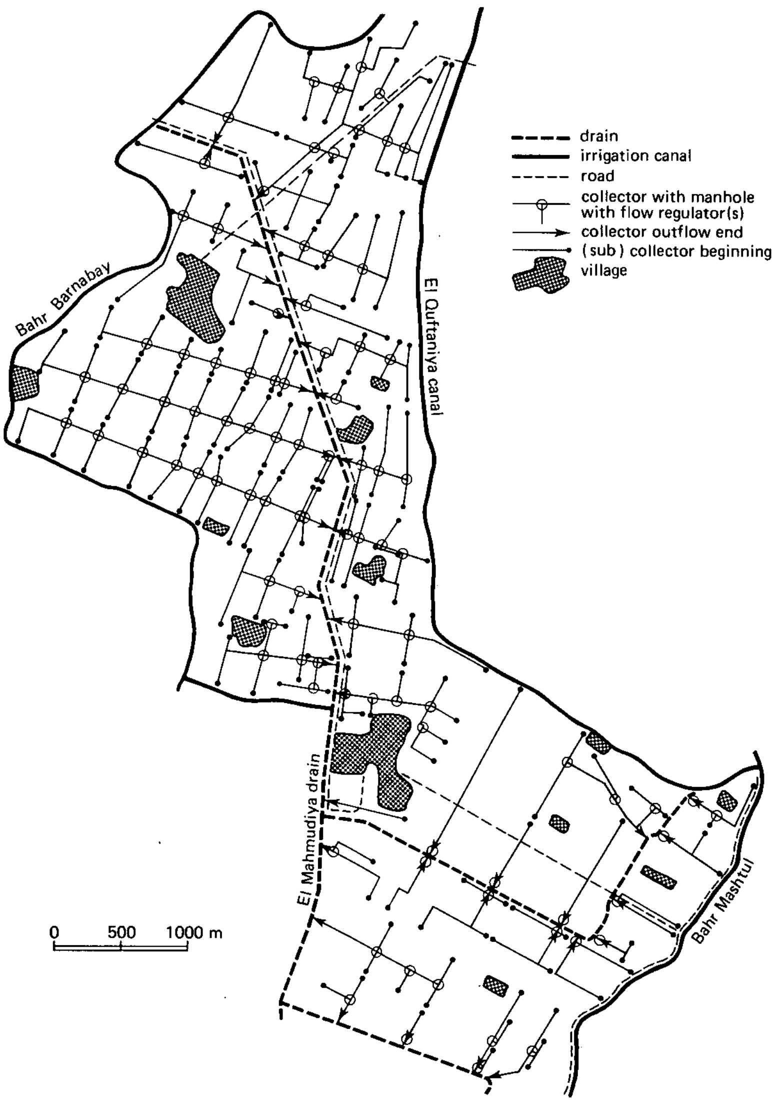


Figure 4.2a Modified layout of the subsurface drainage system in the Mahmudiya I area

The cost comparison for another area, i.e. the Nashart area in the Central Delta, also favoured the modified system, resulting in a 6% cost saving (DRI, 1986a).

As yet, no data are available on the operation and maintenance costs of either system. The operation and maintenance costs of the modified system may only be slightly higher than the conventional system. The incremental costs would be attributable to the control devices and would have no noticeable influence on the cost comparison.

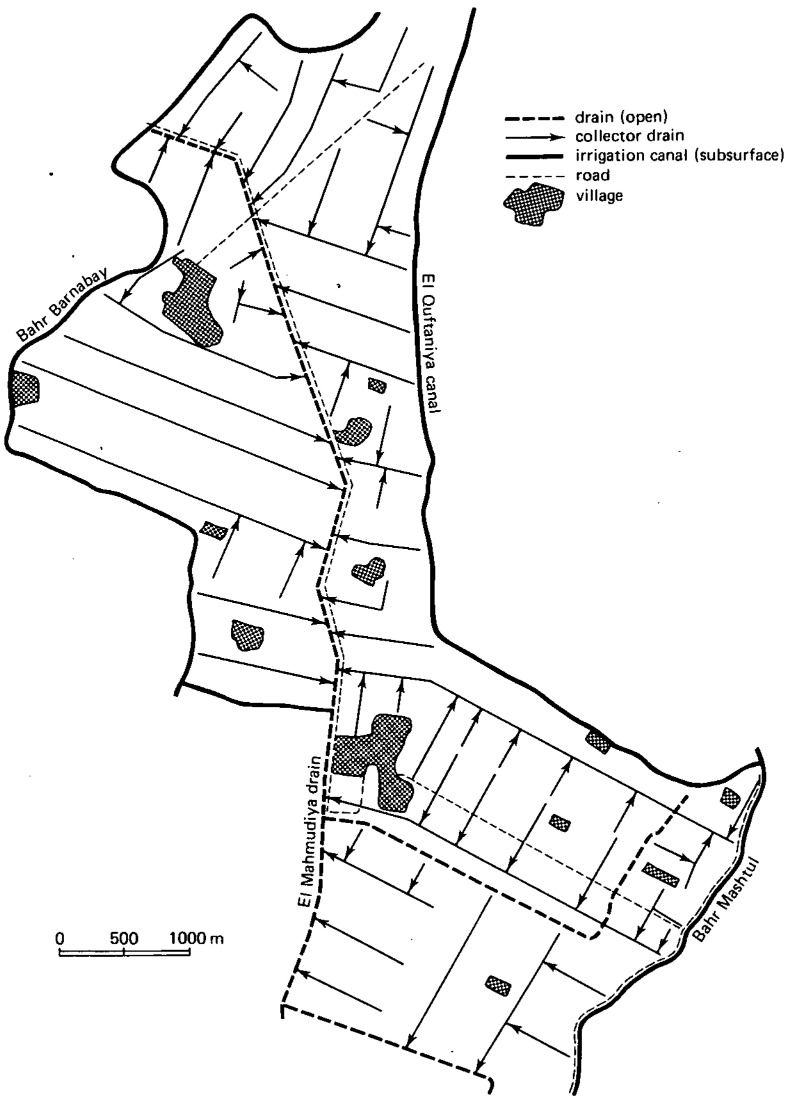


Figure 4.2b Conventional layout of the subsurface drainage system in the Mahmudiya I area

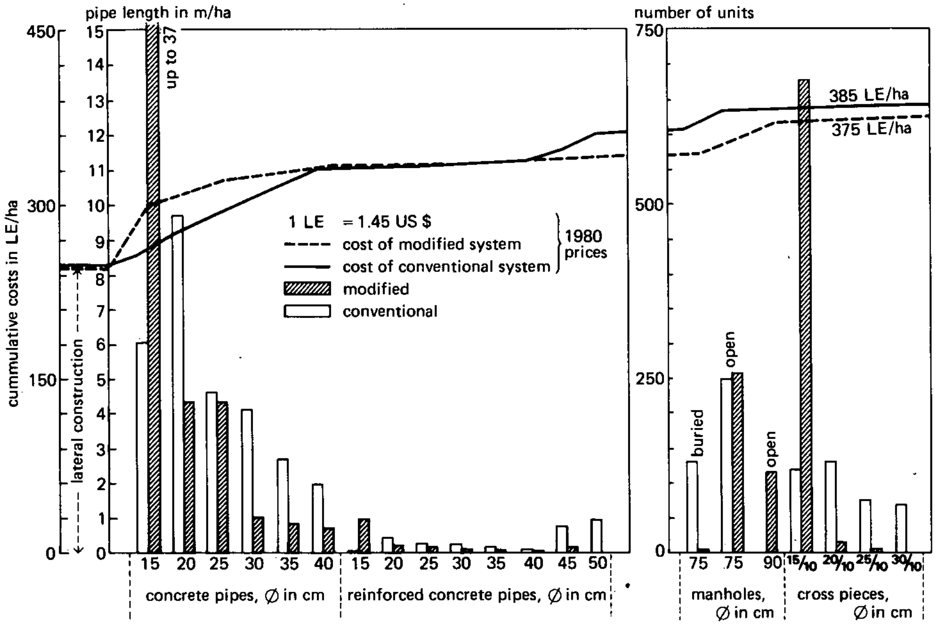


Figure 4.3 Cost comparison between the conventional and modified system

4.3.4 Monitoring

The monitoring programme in the Mashtul pilot area started in the summer of 1981. From 1983 the programme covered the Mahmudiya I and II areas. It was conducted during the rice growing season for three consecutive years. Its objectives were mainly:

- To test the consistency of the crop consolidation scheme and its usefulness in designing the modified drainage system;
- To test closing devices;
- To measure drain discharges;
- To quantify the saving in irrigation water;
- To measure the effect of the modified system on soil salinity.

4.3.5 Results and discussion

Crop consolidation

The consistency of the cropping units is very important for the operation of the modified drainage system. Changes in the cropping pattern may lead to operational problems in the event that another summer crop is grown with rice in the same subcollector unit. In the Mahmudiya area the summer crops are grown according to a three-year crop rotation. This means, for example, that the cropping pattern of 1985 should be the same as that of 1982. There would be no operational problems if the total area of subcollector units were to change to another crop than expected on the basis of the three-year crop rotation. Operational problems could, however be expected if changes involve more than one crop being grown in one drainage unit. The changes in the Mahmudiya I area of each crop between the summer season of 1982 and 1985 are presented in Table 4.1.

These changes, if consistent for the years to come, could lead to operational problems over a total area of 42.4 ha (3%), while changes having no effect on the operation of the system would cover an area of 152.5 ha (9%). 88% of the area had the same cropping pattern as that in 1982.

In 1985 the total area with actual operational problems was 41.2 ha (2%). The areas per crop were 1% (cotton), 5% (maize), and 2% (rice). The small cropping units around villages, which had to be integrated into subcollector units of practical sizes, gave rise to problems. This could easily have been solved by adjusting the cropping units. A procedure for this has still to be developed by 'Irrigation' and 'Agriculture'. It can be concluded that the crop consolidation plans form a good and reliable basis for preparing the layout of the modified drainage system. The deviations in the boundaries of the cropping units from the subcollector units are within acceptable limits. More than 95% of the area has a far more manageable drainage system compared with the conventional design.

Table 4.1 Changes in cropping patterns in the Mahmudiya I area

Crop	Actuel cropping pattern 1982	Potential operational problems				No operational problems				Actual cropping pattern 1985	Ratio 1985/ 1952
	Total area (ha)	Increase in area (ha)		Decrease in area (ha)		Increase in area (ha)		Decrease in area (ha)		Total area (ha)	
Cotton		M→C	R→C	C→M	C→R	M→C	R→C	C→M	C→R		
	523	6.7		11.8	3.4	34.0	21.4	0.8	4.2	568	1.08
Maize		C→M	R→M	M→C	M→R	C→M	R→M	M→C	M→R		
	627	11.8	14.3	6.7	6.3	0.8	28.2	34.0	63.9	571	0.91
Rice		M→R	C→R	R→C	R→M	M→R	C→R	R→C	R→M		
	550	6.3	3.4		14.3	63.9	4.2	21.4	28.2	564	1.03
Total	1700	42.4		42.4		152.5		152.5		1700	

M = Maize, C = Cotton, R = Rice

Closing devices

The Drainage Research Institute (DRI, 1987) has developed and tested the folowing closing devices for the subcollector units (Figure 4.4.):
- Conical earthenware plugs;
- Wooden plugs with rubber coating;
- Steel sluice gates.

The earthenware and wooden plugs had the disadvantages that leakages frequently occurred and that they could easily be removed by unauthorized persons. So far, the steel sluice gates were the most practical. They are permanently installed and easy to operate. Rubber strips prevent any leakage. A good coating of lead paint is necessary for protection against rust. The unit cost of the gates, however, is relatively high (LE 20,–)[1]); a cheaper solution is still being sought.

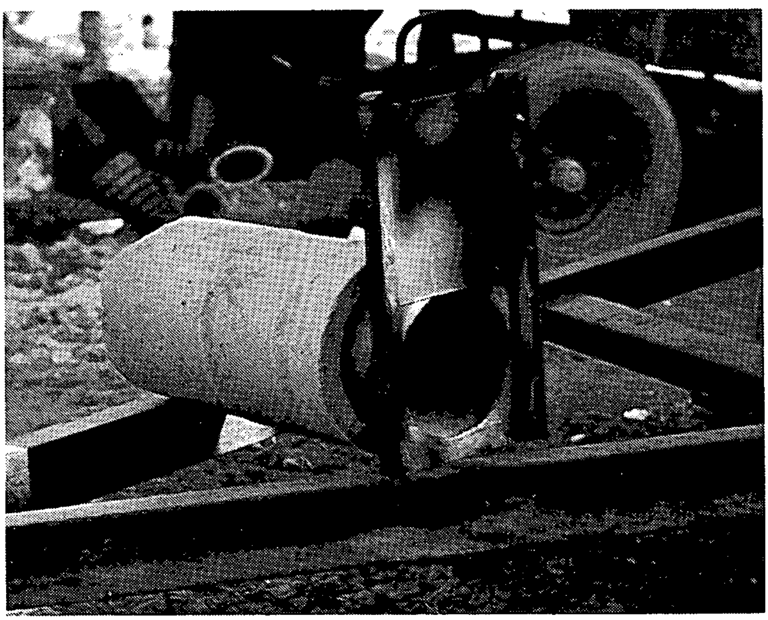


Figure 4.4 Closing device

Drain discharges

The collector discharges were measured in the Mahmudiya I (modified) and the Mahmudiya II (conventional) areas. The outflow of the collectors can be classified into two groups:

[1]) 1985 prices, LE 1.00 = US$ 1.10

- Collectors without outflow from rice fields due to:
  - Closure of subcollectors of the rice area (modified system);
  - Absence of rice crop;
- Collectors with outflow from rice fields which cover a part of the total area drained.

The collector discharges of the first category seldom exceeded 1.0 mm/day. In the second category maximum discharges of 4.5 mm/day were measured.

In Figure 4.5 the average collector discharges are given against the percentage rice area within the collector command area. The average collector discharge with restricted subcollector outflow of the rice areas and of non-rice areas is 0.5 mm/day. This is far below the design discharge of 2 mm/day.

The average collector discharge, with unrestricted outflow from rice areas increases according to the following equation:

$$q = 0.5 + 0.03A,$$

where

q = average collector discharge in mm/day

A = drained rice area within the collector command area, in percent

The correlation coefficient r is 0.81. The 90% confidence limits of the regression coefficient are 0.02 and 0.04, which are significant. The average collector discharge of an entire rice grown area would be 3.5 mm/day.

In the Mashtul pilot area unrestricted outflows of lateral drains under rice fields were measured. The average discharges varied between 3 and 4 mm/day, which agreed with the calculated discharges of rice areas according to the above relationship. Moreover, it confirms the findings in Section 3.4.1, and those of VBB/ILACO (1973).

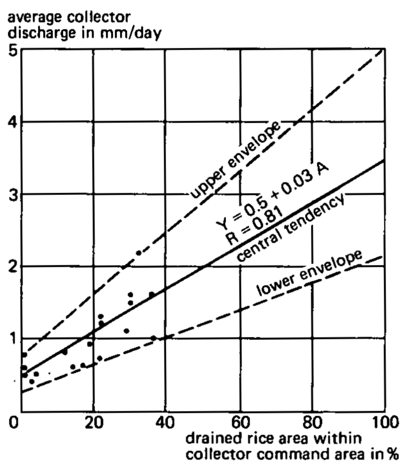


Figure 4.5 Average collector discharges in drained rice areas

Saving in irrigation water

From the data in the previous section it can be concluded that the restriction of the outflow of subcollector units with rice would save at least 3 mm/day. The total area under rice is approximately 420,000 ha. The saving in irrigation water would thus be approximately 12.5 million m^3 per day, or 1.5 billion m^3 per growing season. In view of the increasing demand for irrigation water in Egypt, the implementation of the modified layout in rice growing areas could therefore contribute considerably to the saving of irrigation water.

Soil salinity

An investigation was carried out as to whether the closure of the subsurface drainage system during the rice season would increase the soil salinity. Measurement of the soil salinity before and after the rice season indicate minimal fluctuation (Table 4.2).

Salts were leached from the topsoil in 1983 and 1984. The slight increase in 1985 could easily have been removed during the non-rice season when there was no restriction on the subsurface drainage outflow.

Table 4.2 Soil salinity in the Mahmudiya I (modified) area before and after the rice season

Year	Soil layer in cm	EC_{ex} in mmhos/cm	
		Before	After
1983	0– 25	2.2	1.8
	25– 50	1.9	2.2
	50–100	2.2	2.3
1984	0– 50	1.3	0.9
1985	0– 25	1.0	1.4
	25– 50	1.2	1.4

In experimental fields with a modified subsurface drainage system, the Drainage Research Institute (1986b) found that the soil salinity had decreased by the end of the rice season (Figure 4.6).

The investigations clearly showed that the modified system would not cause soil deterioration.

4.4 Final conclusions

Experience with the modified subsurface drainage system in the Mahmudiya I area was very positive. Water management in rice growing areas in the Delta could be

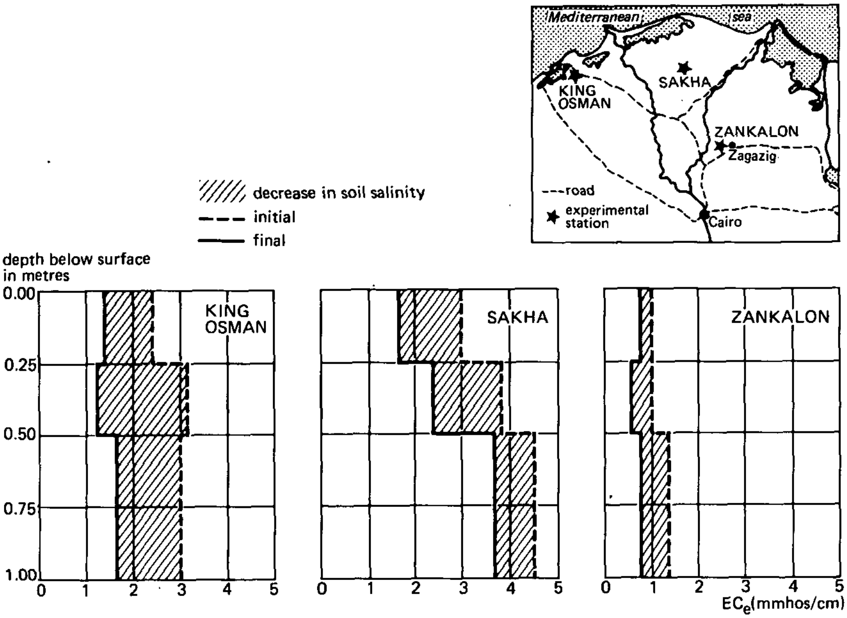


Figure 4.6 Soil salinity before and after the rice season on three experimental fields with a modified system in the Nile Delta (after DRI, 1986b)

considerably improved by applying the modified system. Two other areas have already been designated for further investigations.

To reap the full benefits of the modified system there are, however, still a few items to be considered. These are:

- Consultation between 'Irrigation' and 'Agriculture' on the most suitable drainage units should these units deviate for any reason from the cropping units;
- The planning of the location and delimitation of rice blocks from year to year according to the subcollector units. 'Agriculture' should obtain copies of the drainage layout;
- Operation and maintenance of the closing devices. The similarity with the operation of the irrigation system is striking. Therefore, 'Irrigation' seems to be the obvious choice;
- Extension to the farmers. This work is normally within 'Agriculture's' competence and responsibilities.

The arrangement between the above items should be institutionalized by an agreement between 'Irrigation' and 'Agriculture'.

Bibliography

Abdel Dayem M.S.; J. Deelstra; M. Abdel Moniem et al, 1985. Monitoring the performance of a drainage system with modified layout and comparison with conventional system (summer season, 1984), Technical report No. 30. Drainage Research Institute, Giza/Cairo, Egypt, 136 p.

Aboukhaled A.; A. Arar; A.H. Balba et al, 1975. Research on crop water use, salt affected soils and drainage in the Arab Republic of Egypt. Food and Agricultural Organization of the United Nations, Near East Regional Office, Cairo, Egypt, 92 p.

Advisory Panel for Land Drainage in Egypt, 1977. Water management of tile-drained rice fields. Report No. 77.III.05. International Institute for Land Reclamation and Improvement, Wageningen, The Netherlands, 21 p.

Ayers R.S.; and D.W. Wescot, 1985. Water quality for agriculture. Irrigation and drainage paper 29, rev. 1. Food and Agricultural Organization of the United Nations, Rome, Italy, 174 p.

Cavelaars J.C., 1978. Alternative criteria and principles for the design of drainage networks in rice-growing areas. Report of a visit to Egypt, May 2-12, 1978. Report No. 78.V.02. Advisory Panel for Land Drainage in Egypt. International Institute for Land Reclamation and Improvement, Wageningen, The Netherlands, 15 p.

Cavelaars J.C., 1985. Survey and design for subsurface drainage in Egypt. Report on a consultancy mission in February-March, 1985. Euroconsult, Arnhem, The Netherlands, 88 p.

De Datta S.K., 1981. Principles and practices of rice production. Wiley, New York, USA, 618 p.

Dendy F.E.; and G.C. Bolton, 1976. Sediment yield-run off-drainage area relationships in the United States. Journal of Soil and Water Conservation, 31 (6), pp. 264-266.

De Wolf J.; E. Dahmen; K.J. Lenselink. Water control for lowland rice cultivation, procedures for design. International Institute for Land Reclamation and Improvement, Wageningen, The Netherlands, under preparation.

Drainage Research Institute, 1978. Water management of rice fields (first report). Technical report No. 1. Drainage Research Institute, Giza/Cairo, Egypt, 54 p.

Drainage Research Institute, 1978. Water management of rice fields (second report). Technical report No. 2. Drainage Research Institute, Giza/Cairo, Egypt, 55 p.

Drainage Research Institute, 1984. Monitoring the performance of a drainage system with modified layout and comparison with a conventional system. Technical report No. 27. Drainage Research Institute, Giza/Cairo, Egypt, 74 p.

Drainage Research Institute, 1986a. Design and Monitoring of modified drainage system. Technical report No. 49. Drainage Research Institute, Giza/Cairo, Egypt, 50 p.

Drainage Research Institute, 1986b. Water management in rice fields under conventional and modified drainage concepts. Technical report No. 50. Drainage Research Institute, Giza/Cairo, Egypt, 145 p.

Drainage Research Institute, 1987. Closing devices for subcollector operation in a modified drainage system. Technical Bulletin No. 15. Drainage Research Institute, Giza/Cairo, Egypt, 11 p.

El Gabaly M.M, 1978. Rice soils of Egypt and other Near East Countries. Soils and Rice. International Rice Research Institute, Los Banos, The Philippines, pp. 135-146.

Ezaki K., 1975. Drainage of paddy fields in Japan. Symposium on water management in rice field. Proceedings of a symposium on Tropical Agriculture Researches. Research Series No. 9. Tropical Agriculture Research Centre, Ibaraki, Japan, pp. 273-282.

Ezekiel M.; and K.A. Fox, 1959. Methods of correlation and regression analysis: linear and curvilinear. Wiley, New York, USA, 548 p.

Kirkham D., 1957. The ponded water case. In: Drainage of Agricultural Lands. American Society of Agronomy, Madison, USA, pp. 139-181.

Ley T.W.; and R.L. Tinsley, 1983. Irrigation and production of rice in Abu Raya, Kafr el-Sheikh Governorate. Technical report No. 9. Egypt Water Use and Management Project Cairo, Egypt, 64 p.

Metawie A.B.; T.W. Ley; and R.L. Tinsley, 1981. Small-farm rice irrigation in Egypt. American Society of Agricultural Engineering, Paper No. 81-5502, 24 p.

Moormann F.R.; and N. van Breemen, 1978. Rice: Soil, Water, Land. International Rice Institute, Los Banos, The Philippines, 185 p.

Nijland H.J., 1983. Economic evaluation of land drainage in Egypt: Final report crash programme 1978-1981. International Institute for Land Reclamation and Improvement, Wageningen, The Netherlands, 58 p.

Nijland H.J.; and S. El Guindy, 1984. Crop yields, watertable depth, and soil salinity in the Nile Delta, Egypt. Annual Report 1983. International Institute for Land Reclamation and Improvement, Wageningen, The Netherlands, pp. 19-29.

Nijland H.J.; and S. El Guindy, 1986. Crop production and topsoil/surface water salinity in farmers' irrigated fields, the Nile Delta. In: Proceedings of the 2nd International Conference on Hydraulic Design in Water Resources Engineering: Land Drainage, Southampton University, UK, April 1986, K.V.H. Smith and D.W. Rycroft (ed.), Springer, Berlin, pp. 383-392.

Ramadan F.M.; A. Gharbauwy; W. van Schaik et al., 1981. Design principles and practices for subsurface drainage systems. Applied to crop consolidated areas with rice in the crop rotation. A case study for the Mahhmudiya-I area of '4000' feddan located in the East Bahr Saft Area in the eastern part of the Nile Delta in Egypt. Technical report No. 11. Drainage Research Institute, Giza/Cairo, Egypt, 41 p.

Richards L.A., 1954. Diagnosis and improvement of saline and alkaline soils. Agriculture Handbook No. 60. United States Department of Agriculture, Washington D.C., USA, 160 p.

Risseeuw I.A.; and S. El Guindy, 1982. Water management of rice fields, part III. Technical report No. 19. Drainage Research Institute, Giza/Cairo, Egypt, 83 p.

Said N.F.; M. Atfi; Abdel Meguid et al, 1980. Design of drainage systems in rice areas. Report of a consultancy to the Drainage Research Institute, Giza/Cairo, Egypt. Report No. 81.VIII.03 Advisory Panel for Land Drainage in Egypt. International Institute for Land Reclamation and Improvement, Wageningen, The Netherlands, 21 p.

Snedecor G.W.; and W.G. Cochran, 1967. Statistical methods. Iowa State University Press, Ames, USA, 593 p.

Soong S.T.; and Z. Wei, 1985. Subsurface drainage of lowland rice fields in China. In: Soil physics and rice. International Rice Research Institute, Los Banos, The Philippines, pp. 351-366.

Suh S.D.; and C.U. Kim, 1977. Study on the effects of crop-yields under subsurface drainage system in the waterlogging paddy fields. Journal of the Korean Society of Agricultural Engineers (in Korean with English summary), 19 (3), pp. 35-47.

Tabuchi T., 1985. Underdrainage of lowland rice fields. In: Soil physics and rice. International Rice Research Institute, Los Banos, The Philippines, pp. 147-159.

Tada A., 1976. Irrigation and Drainage Technique in paddy field. Farming Japan, 10 (6), pp. 20-27.

Ten Have H.; I.A. Risseeuw; and J. de Wolf, 1977. Preliminary report on 'Water management of tile-drained rice fields'. In Report of a visit to the Arab Republic of Egypt, Annex 2. Report No. 77.III .02, Advisory Panel for Land Drainage in Egypt. International Institute for Land Reclamation and Improvement, Wageningen, The Netherlands, 13 p.

United Nations Development Programme/Food and Agriculture Organization of the United Nations, 1966. Pilot project for drainage of irrigated land, United Arab Republic. Report of NEDECO/ILACO, Volumes I-IV, No. SF 4/5 UAR/1. Food and Agriculture Organization, Rome, Italy.

United Nations Development Programme/Food and Agriculture Organization, 1979a. Mid-term review report, ROK/75/006. United Nations Drainage Improvement Project of Korea, Seoul, Korea, 110 p.

United Nations Development Programme/Food and Agriculture Organization, 1979b. Provisional guidelines for subsurface drainage of Korea. United Nations Drainage Improvement Project of Korea, Seoul, Korea, 74 p.

Van Alphen J.G., 1975. Some notes on the reclamation of salt-affected soils in Peru. In: Proceedings of the international conference on waterlogging and salinity. Lahore, Pakistan, pp. 332-338.

Van Alphen J.G., 1984. Rice in the reclamation of salt-affected soils. Annual report 1983. International Institute for Land Reclamation and Improvement, Wageningen, The Netherlands, pp. 9-18.

Van de Goor G.A.W., 1967. Rice as a reclamation crop for saline soils. Annual report. International Institute for Land Reclamation and Improvement, Wageningen, The Netherlands, pp. 46-55.

Vattenbyggnadsbyran/International Land Development Consultants, 1973. Nile Delta Drainage Project. The Drainage Engineer's final report. International Land Development Consultants, Arnhem, The Netherlands, 50 p.

Water Distribution Research Institute, 1984. Improving Egypt's irrigation system in the old lands. Egypt Water Use and Management Project, Cairo, Egypt, 68 p.

Wickham T.H.; and V.P. Singh, 1978. Water movement through wet soils. In: Soils and rice. International Rice Research Institute, Los Banos, The Philippines, pp. 337-358.
Yun-sheng C., 1983. Drainage of paddy soils in Taihu Lake region and its effects. Soil Research Report No. 8. Institute of Soil Science, Academia Sinica, Nanjing, China, p. 18.

Currently available ILRI publications

No.	Publications	Author	ISBN No.
11	Reclamation of salt-affected soils in Iraq.	P. J. Dieleman (ed.)	–
14	Irrigation requirements for double cropping of lowland rice in Malaya.	G. A. W. van de Goor and G. Zijlstra	90 70260 840
15	Planning of service centres in rural areas of developing countries	D. B. W. M. van Dusseldorp	–
16	Drainage principes and applications (in 4 volumes)	–	90 70260 123, –131, –62 X and –63 8
16^S	Principos y aplicationes del drenaje (en 4 volúmenes).	–	–
17	Land evaluation for rural purposes.	R. Brinkman and A. J. Smyth	90 70260 859
19	On irrigation efficiencies.	M. G. Bos and J. Nugteren	90 70260 875
20	Discharge measurements structures.	M. G. Bos	–
21	Optimum use of water resources.	N. A. de Ridder and A. Erez	–
23	Land evaluation for agricultural development.	K. J. Beek	–
24	Drainage and reclamation of salt-affected soils.	J. Martinez Beltrán	–
25	Proceedings of the International Drainage Workshop	J. Wesseling (ed.)	90 70260 549
26	Framework for regional planning in developing countries	J. M. van Staveren and D. B. W. M. van Dusseldorp	90 70260 832
27	Land reclamation and water management.	–	90 70260 689
29	Numerical modelling of groundwater basins: A user-oriented manual	J. Boonstra and N. A. de Ridder	90 70260 697
30	Proceedings of the Symposium on Peat Lands Below Sea Level.	H. de Bakker and M. W. van den Berg	90 70260 700
31	Proceedings of the Bangkok Symposium an Acid Sulphate Soils.	H. Dost and N. Breeman (eds.)	90 70260 719
32	Monitoring and evaluation of agricultural change.	Josette Murphy and Leendert H. Sprey	90 70260 743
33	Introduction to farm surveys.	Josette Murphy and Leendert H. Sprey	90 70260 735
34	Evaluation permanente du développement agricole.	Josette Murphy and Leendert H. Sprey	90 70260 891
35	Introduction aux enquêtes agricoles en Afrique.	Josette Murphy and Leendert H. Sprey	90 70260 956
36	Proceedings of the International Workshop on Land Evaluation for Extensive Grazing (LEEG).	W. Siderius (ed.)	90 70260 948
37	Proceedings of the ISSS Symposium on 'Water and solute movement in heavy clay soils'.	J. Bouma, P. A. C. Raats (ed.)	90 72060 972
38	Aforadores de caudal para canales abiertos.	M. G. Bos, J. A. Replogle and A. J. Clemmens	90 70260 921
39	Acid Sulphate Soils: A baseline for research and development.	D. Dent	90 70260 980
40	Land evaluation for land-use planning and conservation in sloping areas.	W. Siderius (ed.)	90 70260 999
41	Research on water management of rice fields in the Nile Delta, Egypt.	S. EL. Guindy & I. A. Risseeuw; H. J. Nijland (Ed.)	90 70754 08 8
No.	Bulletins		
1	The auger hole method.	W. F. van Beers	90 70260 816
4	On the calcium carbonate content of young marine sediments.	B. Verhoeven	–

No.	Bulletins	Author	ISBN No.
6	Mud transport studies in coastal water from the Western Scheldt to the Danish frontier.	A. J. de Groot	
8	Some nomographs for the calculation of drain spacings.	W. F. J. van Beers	–
9	The Managil South-Western Extension: An extension to the Gezira Scheme.	D. J. Shaw	–
10	A viscous fluid model for demonstration of groundwater flow to parallel drains.	F. Homma	90 70260 824
11	Analysis and evaluation of pumping test data.	G. P. Kruseman and N. A. de Ridder	90 70260 808
11S	Análisis y evaluación de los datos de ensayos por bombeo.	G. P. Kruseman and N. A. de Ridder	–
11F	Interprétation et discussion des pompages d'essai.	G. P. Kruseman and N. A. de Ridder	–
12	Gypsifereous Soils.	J. G. van Alphen and F. de los Rios Romero	–
13	Groundwater hydraulics of extensive aquifers.	J. H. Edelman	90 70260 794
No.	**Bibliographies**		
7	Agricultural extension in developing countries.	C. A. de Vries	–
8	Bibliography on cotton irrigation.	C. J. Brouwer and L. F. Abell	–
9	Annotated bibliography on surface irrigation methods.	S. Raadsma, G. Schrale	–
10	Soil Survey interpretation.	R. H. Brook	–
13	Abstract journals on irrigation, drainage and water resources engineering.	L. F. Abell	–
18	Drainage: An annotated guide to books and journals.	G. Naber	90 70260 93 X
	Other publications		
	Papers International Symposium Polders of the World (3 volumes).		90 70260 751 76 X and –778
	Final Report Symposium Polders of the World.		–