CONTROLLED DRAINAGE STRATEGIES TO SAVE WATER IN SEMI-ARID AGRICULTURAL AREAS SUCH AS THE NILE DELTA, EGYPT

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ABSTRACT

Current global population growth rates require an increase in agricultural food production of about 40-50% over the next thirty to forty years, in order to maintain present levels of food intake. To meet the target, irrigated agriculture must play a vital role, in fact the FAO estimates that 60% of future gains will have to come from irrigation.

The practice of controlling drainage involves the extension of on-farm water management to include drainage management. With the integration of irrigation and drainage management, the water balance can be managed to reduce excess water losses and increase irrigation efficiencies.

Controlled drainage is relatively new and there are many theoretical and practical issues to be addressed. The technique involves maintaining high water table in the soil profile for extended periods of time, requiring careful management to ensure that crop growth is not affected by anaerobic conditions.

A fieldwork programme has been investigated to test controlled drainage in the Nile Delta, where water resources are stretched to the limit. Water saving is essential in the next 20 years. Pressures from the fixed Nile water allocation, population growth, industry and other sectors and the horizontal expansion programme mean that this need is urgent.

One crop season has been completed at a site in the Western Nile Delta using simple control devices in the subsurface drainage system. This paper discusses the potential benefits of controlled drainage to save water in agricultural areas such as the Nile Delta, and presents findings from the first crop season.

INTRODUCTION

Current global population growth rates require an increase in agricultural food production of about 40-50% over the next thirty to forty years, in order to maintain present levels of food intake. To meet the target, irrigated agriculture

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must play a vital role; in fact the FAO estimates that 60% of future gains will have to come from irrigation. For this to happen two major constraints must be overcome – irrigated agriculture must use water more efficiently and quality of water and soil resources must be maintained.

Irrigated agriculture is a major global water user. Two thirds of all water abstracted from rivers and underground aquifers are used for irrigation, in the developing world the proportion is even higher. Water is typically used inefficiently with wastage of water supplies, transfer of pollutants to groundwater, and waterlogging and salinization of the root-zone.

In semi-arid areas there is often the need to supply extra water for salt-leaching purposes, which leads to a consistent volume of water percolating below the crop root zone and downwards until it meets the local water table. Over many years this over-irrigation has caused the water table to rise close to the crop root zone and the soil surface, necessitating the need for water table control by artificial drainage.

Artificial drainage for water table control commonly takes the form of open ditches at field edges and subsurface drains laid horizontally across fields at a depth of 1-2m and spacing of 20-80 m. In the majority of cases, drainage systems are over designed (it is often policy to design for the crop most sensitive to waterlogging) and irrigation applications are inefficient. The combined effect is that drainage rates often exceed evapotranspirative demands and the drainage system removes water from the soil, so it is no longer available to meet ET demands.

Loss of excess water through drainage is often a major component of inefficiency in irrigation systems. Controlled drainage is a practice that allows farmers to control drainage outflows, storing water in the soil profile for use by the crop and reducing losses from the system. Water management at the field-level has traditionally been thought of only as irrigation management. When irrigation management is integrated with drainage management this opens up new opportunities for water saving, increased insurance against crop losses due to water shortage, and possible water quality benefits.

This paper describes initial findings of an ongoing project to develop integrated irrigation and drainage management strategies incorporating controlled drainage, to save water and protect water resources in semi-arid regions such as the Nile Delta. The project (DFID KAR contract R7133) is being carried out by the Water Management Department of HR Wallingford in collaboration with the Drainage Research Institute of the National Water Research Centre, Egypt.

CONTROLLED DRAINAGE

Drainage systems in irrigated agricultural areas are traditionally designed solely to maintain agricultural productivity by controlling (saline) high water tables. Systems are designed to remove water rapidly from the soil profile. With conventional farming practice there is irrigation management, but no drainage management, and large volumes of water leave the soil profile through the subsurface drainage system. This constitutes a major factor in the water loss from many agricultural areas. Water quality protection and water saving aspects are not addressed. As a result (Grismer and Tod, 1991) significant root zone percolation and solute load can bypass drains and move to the deep aquifer for groundwater deterioration, and useful water is often lost from the soil profile without the crop having the chance to use it.

The practice of controlling drainage involves the extension of on-farm water management to include drainage management. With the integration of irrigation and drainage management, the water balance can be managed to reduce excess water losses and increase irrigation efficiencies.

With controlled drainage the farmer is able to control the amount of water leaving the land. A weir (or other control structure) or blocking device is used to control drainage outflows. Gravity or pumped drainage occurs only after the water level in the drainage ditch, pump sump or water table in the field has risen to a level where drainage should be provided to prevent crop damage or provide salt leaching. To attain this, drainage is stopped or restricted by some device when the water table or ditch level drops to a certain level. When the water table rises above this point (by rainfall or irrigation) free drainage occurs again.

Controlled drainage is relatively new and there are many theoretical and practical issues to be addressed. The technique involves maintaining high water tables in the soil profile for extended periods of time, requiring careful management to ensure that crop growth is not affected by anaerobic conditions.

To prevent accumulation of solutes (particularly salts) in the root zone it is necessary to maintain leaching processes. With proper management, controlled drainage techniques should improve efficiency of solute removal in drain flow and protect the crop root zone and groundwater resources.

There has been research into controlled drainage, primarily in humid areas, and it has been adopted in several locations. Countries include USA, Canada, Bulgaria, Poland, Finland and Holland. The main benefits (depending on location) have been identified as:

- Yield increases.
- Water and energy savings.
- Water quality protection

Most of the work to date has been in humid areas, but controlled drainage is likely to be beneficial in many arid and semi-arid regions of the world, where water tables are high. Potential areas of application include Egypt, Pakistan and India.

Controlled drainage is suited to areas with a high water table. Blocking of drains allows the irrigation water to remain in the field close to the crop root zone for a sustained period of time. This water is then fully available to the crop.

In theory, if the amount of water applied by irrigation is equal to the crop water requirements then water could be applied indefinitely and the water table level would remain stable. However, in semi-arid areas a leaching requirement is necessary to wash the salts out of the root zone (Manguerra and Garcia 1997). This extra water means that the water table will rise steadily over a couple of growing seasons. A period of drainage is therefore required to flush out the excess water and salts. According to predictions in California, if the drains are not opened for consecutive growing seasons, the crop will be subjected to excessive waterlogging during the third season (Manguerra and Garcia 1996).

The work concluded (Evans *et al*, 1996) that when controlled drainage was applied all year it reduced total outflow by approximately 30 percent compared to conventional systems, although outflows varied widely depending on soil type, rainfall, type of drainage system and management.

POTENTIAL AND CONSTRAINTS FOR APPLICATION OF CONTROLLED DRAINAGE IN EGYPT

Egypt's existence depends on the River Nile, the largest renewable source of fresh water in northern Africa. It provides, almost exclusively, the source of water for agriculture, industrial and domestic use in this extremely arid land, and is a major fishery throughout its length. The agricultural sector is the largest water consumer, using about 85% of Egypt's surface water resources at present. A network of about 30,000km of irrigation canals and 17,500km of drainage channels serve the estimated 7.4 million feddans (1 feddan = 4200 m^2) of irrigated land in Egypt.

The Government of Egypt has embarked on an ambitious horizontal expansion program to increase the total irrigated land area using the fixed water allocation of 55.5 bcm/yr. Major projects include:

- Toshka Project – designed to develop 0.5 million feddans of desert land in Upper Egypt for agricultural production in the next 10-20 years taking up to 5 bcm/yr of river Nile flow from Lake Nasser.

- Salam Canal Project – to divert 2 bcm/yr drain water from the Bahr Hadus and Lower Serw drain basins in the Eastern Delta for 200,000 feddans irrigated area in west Suez and 400,000 feddans reclamation in Sinai. Irrigation has started in west Suez and reclamation will commence shortly in Sinai.

- Umoum Drain Project – to reuse 1 bcm/yr of drain water from Umoum drain basin in the Western Delta for 0.5 million feddans irrigation in Nubaria. Physical works are underway.

These projects will have major impact on the water balance of the Nile Delta. Water savings are imperative. Major strategies adopted within the country include reusing drain water for irrigation, and improving irrigation management in the Delta.

Agricultural areas of the Nile Delta have three attributes that immediately suggest controlled drainage would be appropriate and beneficial:
- High water table in many locations.
- Extensive subsurface drainage system.
- High drainage flows – constituting a major water loss at field scale.

In fact there have been (and still are) studies into controlled drainage in Egypt, but these have only considered controlled drainage under **rice**, and not addressed potential benefits under dry-foot crops.

Two major studies were carried out by DRI (rice seasons 1996 and 1997) in farmers' fields in the Balaktar area of the Western Delta, east of Damanhur City in Beheira Governerate (DRI, 97 and DRI, 98). These studies demonstrated the significant potential for controlled drainage (with modified drainage design) to save water under rice field. This programme is ongoing, with efforts focusing on mechanisms to implement the approach on a large-scale in rice areas. Although work to date on controlled drainage in Egypt has identified major potential savings in water under rice, no work has been done to assess possible benefits under other crops.

SIMULATION MODEL

The water management simulation model DRAINMOD-S (Kandil et al, 1992), a modified version of the original DRAINMOD (Skaggs, 1978) which is based on a water balance in the soil profile, was chosen for this study. The model was developed in Fortran for the design and evaluation of multi-component water management systems on shallow watertable soils in humid regions, it has subsequently been extended and successfully applied in semi-arid areas (Kandil, et al 1995 and Gupta et al, 1993). DRAINMOD-S allows salt concentrations in the soil profile and drainage water to be calculated throughout the season.

The model is a field water balance model developed and refined over many years. It computes daily water and salt balance and water table depths, and seasonal crop yields. It allows simulation of conventional and controlled drainage using weirs, and has been applied and verified in semi-arid regions including the Nile Delta.

Simulation of Water Management Strategies

The DRAINMOD-S model was used to develop controlled drainage strategies for 6 scenarios of water availability – ranging from the current water use scenario, through scenarios of summer and winter water shortage to a year-round reduction in water available for irrigation. These results are summarised in Table 1 below:

Table 1. Irrigation Amounts (mm) Applied under the Demonstration Scenarios

	Normal (current situation)	Summer Water Shortage	Winter Water Shortage	Increased Summer Water Shortage	Increased Winter Water Shortage	Year-Round Water Shortage
Cotton	779.3	701.8	779.3	612.4	779.3	612.4
Wheat	559.6	559.6	511.8	559.6	429	429
Maize	750.6	662.7	750.6	607.3	750.6	607.3
Berseem	365.8	365.8	224.1	365.8	142.6	142.6
Rotation Total (% water use)	2455.3 (100%)	2290 (93%)	2265.8 (92%)	2145 (87%)	2101.5 (86%)	1791.3 (73%)

The input data for the DRAINMOD-S model for soil, climatic, irrigation, drainage design and crop data are collected from the Maruit site in the Western Nile Delta.

For each water use scenario, the tool was used to assess water and salt balance, crop response and farmer costs for conventional irrigation and drainage operation, and eight to ten proposed controlled drainage designs. The controlled drainage strategies were based on setting different weir depths during crop seasons as outlined in Table 2 below.

Table 2. Controlled Drainage Strategies

Drainage Strategy	Controlled Drainage Crops	Months CD applied	Weir depth
CONV	None	None	None
CD1	Cotton	April – Oct	60cm
CD2	Cotton	April – Oct	90cm
CD3	Wheat	Oct – April	60cm
CD4	Wheat	Oct – April	90cm
CD5	Maize	May – Sept	60cm
CD6	Maize	May – Sept	90cm
CD7	Berseem	Oct – Feb	60cm
CD8	Berseem	Oct – Feb	90cm
CD9	Combination	Varies	Varies
CD10	Combination	Varies	Varies

A total of 63 cases (6 water-use scenarios, with conventional irrigation and drainage, and eight to ten proposed controlled drainage designs) were assessed over a 20-year period, using a 2-yearly crop rotation of cotton, wheat, maize and berseem. This crop rotation is considered one of the most common crop rotations in the Nile Delta.

A predictive design tool (Microsoft Excel with Visual Basic programme) was thus used to identify controlled drainage strategies that satisfied the following criteria:

- Reduced irrigation water use (compared to current irrigation applications under conventional irrigation and drainage).
- Strategies are sustainable. This was defined as no overall increase in soil salinity levels over the 20-year simulation period, and no increase in drain flow.
- Crop yields should be maintained (compared to conventional option with current water use). Average seasonal crop yields to be greater than 95%, and no single crop season with below 90% crop yield.
- Farmer costs should be reduced or stay the same.

The results are summarised below in Table 3.

Table 3. Water Saving Controlled Drainage (CD) Strategies

Strategy	Description	Water Saving
3CD3	CD during wheat season Oct-April, weir set at 60cm	8%
3CD9	CD during wheat season Oct-April, weir set at 60cm AND CD during cotton season April-Oct, weir set at 90cm	8%
5CD9	CD during berseem season Oct-Feb, weir set at 90cm AND CD during wheat season Oct-April, weir set at 60cm	14%
5CD10	CD during berseem season Oct-Feb, weir set at 90cm AND CD during wheat season Oct-April, weir set at 60cm AND CD during cotton season April- Oct, weir set at 90cm	14%

Four controlled drainage designs satisfied the criteria, offering water savings of 8 and 14% on an annual basis. All four strategies allowed reduced irrigation applications during the winter months, when wheat and berseem were grown.

The most beneficial controlled drainage design (of the ones tested) was found to be a weir setting of 60cm during the wheat crop season from October to April. This option featured in all four beneficial strategies. The "best" design (high water saving, highest crop yields) was found to be a combination of controlled drainage in three crop seasons – weir depths of 90cm during berseem, 60cm during wheat and 90cm during cotton seasons.

FIELD APPLICATION OF CONTROLLED DRAINAGE

Experimental Site

The field study is currently being carrying out at the Maruit experimental station, which is located about 35 km south of Alexandria City. The soil of the site is classified as clay loam to sandy clay loam. The measured hydraulic conductivity by using the auger hole method is about 2 m/day. The soil is considered to be representative for the soil of western Delta of Egypt.

The area is served by a new subsurface drainage system installed in May 1999. The collector drains (PVC corrugated plastic pipe) have been installed at about 1.5 m depth and the lateral drains (PVC pipe covered by synthetic envelope materials) have been installed at depth 1.2 m with an average spacing about 32 m. As shown in Fig. 1, a water table control device has been designed from special PVC pipe, consisting of three parts. The first part is a horizontal PVC pipe 75-mm diameter connected to the lateral drain in the manhole at the same level as the lateral drain and closed at the end by PVC closed device. The second part is a riser with multi-heights depending on the minimum water table depth and connected vertically with the first connection. The third part is another horizontal PVC pipe 75-mm diameter connected with the riser as a lateral drain at the desired minimum water table depth. This is designed to restrict the drain flow by plugging the original drain outlet. No drainage outflow will occur until the water table level exceeds the desired minimum water table level.

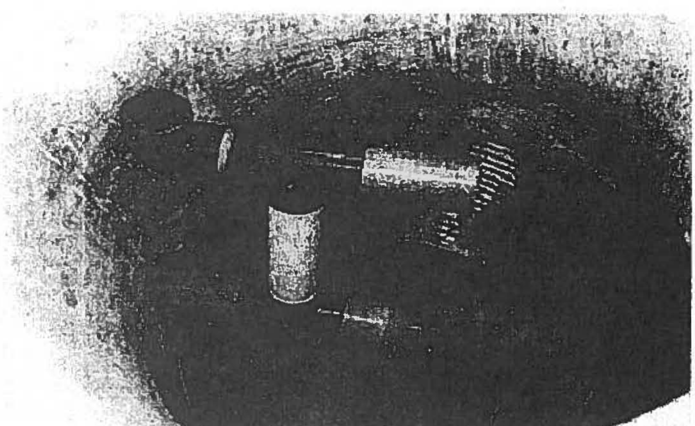

Fig 1. Water table control device

One advantage of this control device is that different riser pipe with different heights can replace the existing riser depending on the root depth and the designed minimum water table depth. No drainage flow will occur until the water table reaches the level of the riser pipe and it is very easy to apply the conventional drainage for leaching by opening the closed device.

Two water table management methods have been applied in the site: the conventional subsurface drainage and the controlled drainage. Each treatment has been applied in an area of about 3 fed (just over 1 hectare) and served by four lateral drains.

The controlled drainage was applied at 60-cm water table depth during the maize cropping season 99. During the crop season the two treatments were applied with the same irrigation water application, the same agricultural management, the same fertilizer application, and the same boundary condition

Data Collection

Soil salinity was determined at the beginning and at the end of the season by taking soil samples at 30-cm interval to 1.2-m depth in different locations of the applied treatments. The ground water depth was measured daily at 32 observation wells covering the study area. The salinity of ground water was measured two times per week at the observation wells by using the EC salinity probe. The soil potential was measured daily at 6 depths in each treatment by using tensiometer profile groups. The rate of drain flow was measured by using bucket and stopwatch at each of the monitored lateral drain outlets. The amount of applied irrigation water for each treatment and also salinity was also measured. Irrigation water, ground water and drainage water samples were collected before and after fertilizer application and analysed for Nitrate –N. Also soil samples were taken at each treatment from 4 depths before each fertilizer application for Nitrate-N analysis The crop yield at harvest time was measured at each treatment by estimating the yield from a specified area.

RESULTS

The results of the summer season of 1999 are as follows:

Ground Water Depths

As shown in Fig. 2 the application of water table control device succeed in raising the water table to the desired level (60-cm) during irrigation time. However the water table was not able to remain at this level due to lateral seepage out of the plots. The main reasons for the lateral seepage are that the permeability of the soil was high (2m/day) and the plot size is small.

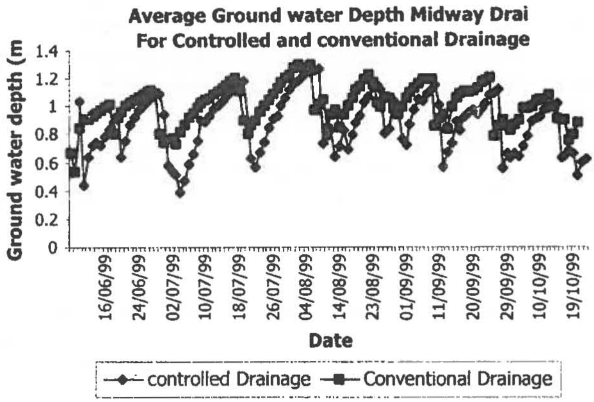

Fig. 2. Ground water depths during summer season 99

Drain Discharge:

The drain discharges for the conventional subsurface drainage and the controlled drainage during the maize season 99 is shown in Fig. 3.

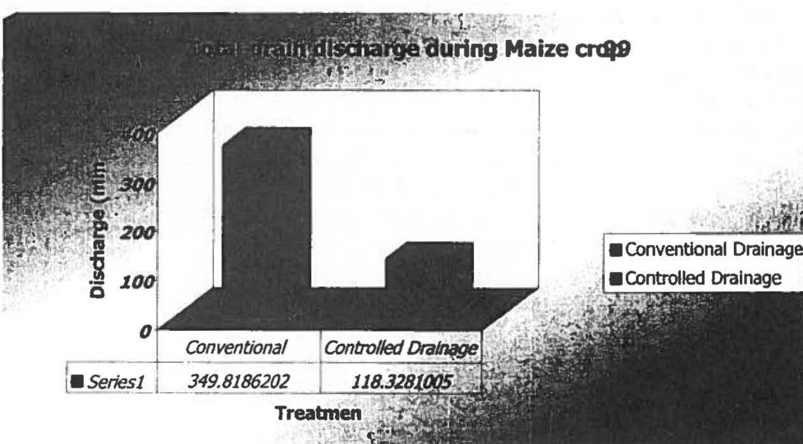

Fig. 3. Total drain discharge during maize crop season 99

The total drain discharge for controlled drainage was about 119 mm and the total drain discharge for the conventional subsurface drainage system was about 350 mm. However, because of high soil hydraulic conductivity, small plot size and low water table in neighboring fields, most of the water in the controlled plot not leaving the field via the subsurface drainage system is leaving the field via lateral seepage. In areas without lateral seepage problems (or in much larger controlled drainage areas), it is likely that this reduction in drainage flow would constitute a significant water saving.

Maize Crop Yield:

The maize crop yield during summer season 99 is shown in Fig. 4. The controlled

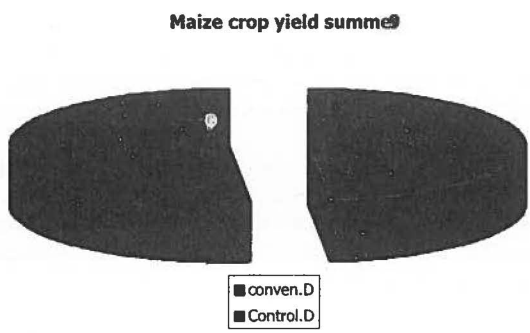

Fig. 4. Maize Crop Yield Summer 99

drainage application gave a crop yield 6.9% higher than the conventional subsurface drainage system. This may be attributed to the improvement of the soil moisture conditions in the root zone area by allowing the water table to raise to a higher level under controlled drainage.

CONCLUSIONS AND RECOMMENDATIONS

- Controlled drainage has been proposed as a water saving management technique for irrigated areas with high water tables and subsurface drainage systems. The technique has been applied (mainly) in humid areas with benefits including:
  - Yield increases.
  - Water and energy savings.
  - Water quality protection.

- Development and application in semi-arid regions is likely to produce similar benefits, but management strategies must incorporate the additional requirement to provide adequate leaching of salts from the soil rootzone.

- A potential and constraints survey was carried out in the intensive agricultural land of the Nile Delta, Egypt, to assess potential benefits and likely constraints to adoption of controlled drainage in such areas. The main conclusions were:

  Water saving is essential in the next 20 years. Pressures from the fixed Nile water allocation, population growth, industry and other sectors and the horizontal expansion programme mean that this need is urgent.

  However the concept of controlling drainage under crops other than rice is new. Farmers appeared sceptical (not uncommon for new ideas) but if the technique maintained (or improved) crop yields and reduced pumping and/or labour costs (as predicted), they would be interested.

- Promising water saving controlled drainage strategies were defined as those that used less water compared to conventional irrigation and drainage practice, yet maintained crop yields, soil and water resources, and reduced farmer costs. Four sustainable controlled drainage designs were developed, that allowed 8 and 14% water saving on an annual basis.

- This demonstration has shown that controlled drainage has the potential to save water, and increase crop yields in periods of water shortage, in semi-arid agricultural areas such as the Nile Delta.

- Fieldwork is underway in the western Nile Delta to test out controlled drainage and compare it to conventional practice.

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