Water Management; Innovative Technology

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Water Saving In Irrigated Agriculture in Egypt

(Case Studies and Lessons Learned)

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Forward

In fact we need many times more units of water for growing our food than for other purposes, about 100 times more at the level of basic existence. Fortunately, much of the water used for growing food is from sources that others cannot use so easily, most obviously direct from rainfall and water is available only in certain seasons.

Watsave concept provides the evidence that as a sector, we really striving for "more crop per drop" and that use of water, although necessarily large, is moving towards even higher levels of productivity.

The ICID publication No.95 (2008) on "Water saving in Agriculture" as prepared by Dr. John, Hennesy president Honoraria ICID, was a rich source of knowledge and reference work leading to prepare this book that focus on study cases and new technology and lessons learned in Egypt, that can provide and promote and enhance experience between member countries of ICID.

As a member of the ICID family, I would like to express my sincere appreciation and gratitude to all professionals and experts from both the Water Management Institute of the National Water Research Center (NWRC) and the Soil, Water and Environmental Institute of the National Agriculture Center of Egypt, for their valuable and endless support during preparing this book.

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Preface

It is now more generally acknowledged that irrigated agriculture is the main engine of growth in most countries economics and can have impacts far beyond the economy of crop production especially in Egypt.

However, irrigation is now coming under increasing scarcity as availability of fresh water resources is shrinking and competition among different water use sectors intensifies.

The major challenge facing irrigated agriculture today is producing more food using less water per unit of output i.e. increasing water productivity in irrigated agriculture. All those involved in irrigation, water management-managers, farmers, workers need to be guided, through appropriate policies and incentives, to save/conserve water and to minimize wastages to mitigate negative environmental impacts. This goal will only be achieved if the appropriate water saving technologies, management tools, and policies are in place. It will be necessary to see as to how innovative ideas and techniques are put in to practice.

All stakeholders from policy makers to farmers need to be roped in this endeavor.

Water management, through reduction of losses and saving will not be enough. The focus, therefore, has to be on both management and development of water resources. Water conservation in Agriculture sector could be achieved by creating storages, reducing conveyance losses, efficient water management. land treatment, reducing water demand, reuse of wastewater, improved O&M of irrigation, rationalization of water rates, integrated use of poor and high quality waters, technology upgrade, etc.

The International commission on irrigation and drainage (ICID) which represents a community of irrigation and drainage professionals concerned to deal with the challenge of sustainable development and management of water resources for sustainable agriculture.

ICID believes that there is a scope for water saving in irrigated agriculture by improving water use efficiency and adopted improved technologies.

Toward this, ICID has published publication (No.95/2008) on “water saving in Agriculture covering some ICID member countries”

Being Egypt is one of the member countries (106 countries) since 1950, found that it is necessary to provide appropriate water management, lessons, technologies and case studies strengthening information dissemination, empowering technology transfer regarding the issues of water saving and conservation not only for Egypt, but also for other ICID, member countries.

The present publication is a compilation in a different form, besides bringing out in a generic sense selected Egyptian experts and research professionals across the land and water resources have contributed to enhance its contents.

The case studies of successful water savings are highlighted and as obvious, water saving efforts are more clearer.

It is hoped that the innovative ideas and practices captured in this publication would be a rich source of knowledge and reference work providing an inspiration for all those professionals engaged in aspiring "more and more crop per drop".

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ABBREVIATIONS

ARC	Agricultural research center
BCM	Billion cubic meter
DRI	Drainage research center
EPADP	Egyptian Public Authority for drainage projects
EC	Electrical conductivity
ESP	Exchangeable sodium percentage
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross domestic product
GIS	Geographic information systems
HRI	Hydraulic research institute
HAD	High Aswan Dam
ICARDA	International center for agricultural research in the Dry Areas
ICID	Internal commission on irrigation and drainage
IFAD	International fund for Agricultural Development
IIIMP	Integrated irrigation improvement and management project
IIP	Irrigation improvement project
IR	Infiltration rate
IWRM	Integrated water resources management
K	Hydraulic conductivity
LF	Leaching fraction
MALR	Ministry of agriculture and land reclamation
MRB	Mechanized raised bed
MWRI	Ministry of Water Resources and Irrigation
NWRC	National Water Research Center
OFIDE	On-farm irrigation development in Egypt
OFIDO	On-farm irrigation development in the old lands
pH	Hydrogen ion concentration
RECTWS	Regional sector for training and water studies
R&D	Research and development
SADS	Sustainable agricultural development strategy

SAR	Sodium adsorption ratio
SFA	Small farmer association
UNESCO	United nations educational scientific and cultural organization
WUA	Water users association
WUG	Water users group

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(By :Dr. Yosri Atta)*

Chapter I

Introduction

Chapter I
INTRODUCTION

1.1 Facts on Egypt's water resources

Egypt's is currently under the water scarcity limit which internationally known as 1000m3/capita/year of renewable water resources to adequately cover, the country: domestic, agricultural, industrial and other basic developmental water needs.

Egypt depends mainly on the Nile Water with a share of 55.5 billion cubic meters per year as indicated in its Nile water agreement with Sudan in 1959. With the continuously increasing population since then, the per capita share of renewable water resources in Egypt has been decreasing from about 2500 m^3/capita/year in 1950's to about 700 m^3/capita/year (year 2015) and is expected to reach 250 m^3/capita/year in 2050.

The increasing gap between the available renewable water resources for Egypt and the water needs reflected by the need to meet water scarcity limit has been fullfilled by:

- Water reuse
- Use of non-renewable groundwater,
- Desalination
- Imports of virtual water embedded in a lot of food products such as, wheat, maize, table oils, meat and others.

1.2. Agriculture relies on irrigation water

The land is dissected by a dense network of water ways, including 50,000 km of canals that branch from the Nile River and convey water to cover 2 million farmers across several geographic area. Alongside are 18,000 km drains where, water is partially re-used by farmers pumped back to higher delivery canals bound from coastal lagoons and the Mediterranean Sea. Of all sectors in Egypt, agriculture is the largest consumer of water representing about 85% of the total water demand. However, because of recent population growth and climate change, the country as a whole are experiencing, severe water scarcity.

Some indicator of the current status of water use in Egypt is shown in the following table (1.1).

Table (1.1) some indicators of the current status of water use in Egypt

Indicator	***Estimate average water use***
Agriculture water (billion m^3)	58
Per capita share of water m^3/year	700
Expected per capita share of water (m^3 /year 2030)	500
Expected per capita share of water (m^3/year 2050)	250
Irrigation water efficiency %	50

With these natural constraints, agricultural growth has been pursued in two directions(Encid 2004).

There has been vertical expansion through:

- Intensification of existing lands, achieved by controlled irrigation management.
- Improved water-use efficiency in horticulture.
- A higher quantity and quality of production per unit of land and water.

At the same time there has been horizontal expansion into desert lands (new lands) involving

- Better management techniques.
- Water saving in the old lands, the irrigated agricultural lands which were claimed from the desert many generations ago and have been intensively cultivated ever.

These two policy approach is motivated by Egypt's:

- Population growth
- Concern about growing dependency on food supply
- The need to compensate for the estimated 22,000 feddans of old lands that are annually lost through urbanization (IPTRID 2005).

Furthermore Egypt is now fully utilizing its share of Nile water resources and continued population and economic growth will exert further pressures on existing water resources.

There are several constraints that need to be addressed in order to achieve sustainable increase in land and water productivity and water use efficiency at different scales in the Nile Delta and Valley. These include identifying and implementing appropriate and sustainable technical options for optimizing water use and saving water through appropriate management.

The focus of this publication is to develop and state comprehensive technical Egyptian experiences throughout papers containing a summary of the facts related to agricultural land in Egypt as a dominant contribution to economic growth in Egypt, the major issues facing the Egyptians water resources and water allocation. The water savings challenges and issues such as:

- Poor infrastructures.
- Low irrigation efficiencies.
- Use of poor quality water for irrigation.
- Use of traditional/conventional irrigation methods.
- The uncertainty of climate change impacts on the water resources of the Nile River.
- Environmental sustainability and very low public awareness in water saving.

As a result it is therefore imperative to develop and promote saving practices on large scale in agriculture to cope with water scarcity. Innovative water saving approaches and case studies are being explored with respect to different crops such as rice, maize, wheat and fruit crops. Other techniques are also explored such as:

- Water saving from on-farm irrigation and drainage development.
- Cropping pattern changes under water scarcity.

This publication is also intended to support directly and indirectly Egypt's, strategy of the four main components:

- The sustainable use of natural and agricultural resources.
- Increasing land and water productivity.
- Raising food security.
- Improving poverty among rural inhabitants.

The information can be useful to researches, practitioners, development agencies and managers but also decision makers, who are interested in Egypt's main agricultural production, systems and the availability and use of water resources in different sectors.

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Chapter 2

Agricultural Lands in Egypt

Chapter 2
AGRICULTURAL LANDS IN EGYPT

2.1 Introduction

Agriculture production is dominant contributor to economic growth in Egypt, accounting for approximately 15% of the country GDP. Moreover, around 55% of the population is dependent on this sector for its livelihood.

Some of the most productive land in the world lies in the Nile Delta, which have more than half of the country's population. Agricultural land amounts to approximately (8.64) million feddans; representing more than 60% of the total cultivated land.

This chapter will include more information about:

- Demographic characterization of Egypt and agriculture
- Types of agricultural land

Fig 2.1 Cultivated lands in Egypt

2.2 The Egyptian agriculture

Egypt has a total land area of approximately 1 million km^2, most of which is desert and only 5.5% is inhabited. Settlements are concentrated in and around the Nile Delta and its valley, which narrows considerably in Upper Egypt. The total cultivated land area is about 3.6 million ha (8.64 million feddan) (Fig 2.1) 3% of the total land area – and consists mostly of old and newly reclaimed areas. The climate is arid with very scarce rainfall in a narrow strip along the north coast. The

Nile River is the main and almost exclusive source of surface water in Egypt. Agriculture depends on the Nile water and consumes between 80 and 85% of its annual water supply.

The agricultural land base consists of old lands in the Nile Valley and Delta, new lands reclaimed from the desert since 1952, rainfed areas, and several oases where groundwater is used for irrigation. The total irrigated area amounts to about 3.60 million ha (8.64 million feddan), and the rainfed areas cover about 84,000 ha (200,000 feddan). Because of the accumulation of salts, mostly at the soil surface, as much as 35% of the agricultural land suffers from a relatively high level of salinity. The majority of the salt-affected soils are located in the north central part of the Nile Delta and on its eastern and western sides.

Geographically and agro-ecologically, Egypt can be divided into five regions (Fig. 2.2):

Upper Egypt, Middle Egypt, Middle Delta, Eastern Delta, Western Delta.

Fig 2.2 Drainage Districts in Egypt

Lake Nasser and Sudan border

Upper or southern Egypt is a narrow river valley, rarely more than 19 km wide, and more frequently only 1.5 or 3 km wide. Middle Egypt is the land between Upper Egypt and the Nile Delta. In the Delta region, which was previously called Lower or northern Egypt, the land is flat and fertile. The Delta is almost 480 km wide at the mouth of the Nile. These lands can also be divided into old lands and new lands. Egypt's population grew from 38 million in 1977 to 90 million in 2015. Despite a decrease in the annual population growth rate in recent years – it is currently 1.8% – the population is expected to reach 93 million by 2017.

2.3 Type of agriculture lands in Egypt

Old lands

The old lands represent the largest irrigated area in Egypt and are found in the Nile Valley and Delta. These include lands which were reclaimed from the desert many generations ago and are intensively cultivated, mostly using water from the Nile. These lands, characterized by alluvial soils and spreading over 2.25 million ha (5.36 million feddan), are irrigated by traditional surface irrigation systems, which compared to modern and improved irrigation systems, have a very low field water application efficiency of around 50%. Most of this land suffers from two important problems, continued encroachment by non-agricultural uses of rate of 8400 ha/year (22,000 to 30,000 feddan/year) and continued degradation of soil fertility.

The results of a land classification based on productivity have shown that the area of first grade lands has declined by approximately one-third, from 1.26 million ha (3 million feddan) on average in 1996-2000 to around 410,000 ha (978,000 feddan) in 2001-2005. The area of second grade lands has also increased from 33.6 to 41.8% during the same period. The area of third grade has also increased from around 0.50 million ha (1.25 million fed.) to approximately 0.9 million ha (2.12 million fed.), while the area of fourth grade lands has increased from 86.000 ha (205.000 fed.) to 340.000 ha (816.000 fed). These data suggest that land improvement program are a top priority.

Assessing the problem of the continued degradation of soil fertility would require undertaking periodic soil surveys as a basis for establishing fertilizer application rates. It would also require continued restoration and maintenance of agricultural drainage systems as well as installing ones where needed to help keep the soil healthy and productive.

In spite of agricultural expansion, land productivity has declined because agricultural rotation was not being followed before liberalization and the incompatibility of the fertilization regimes with the different crops.

The main water related issues of interest in the old lands are to improve on-farm water management by lowering the rising water table and to decrease salinity build-up by improving and developing irrigation and drainage system networks.

New lands

New lands (old new lands and new –new lands) include lands that have been reclaimed relatively recently – particularly since the construction of the Aswan High Dam – or areas that are currently in the process of being reclaimed. They are located mainly on the east and west sides of the Delta and are scattered over various areas of the country. New lands cover 1.05 million. ha (2.5 million feddan). The Nile is the main source of irrigation water, but in some desert areas underground water is used. Sprinkler and drip irrigation regimes are practiced.

Reclamation of these lands started in the early 1950s and is continuing. The government reclaimed approximately 806,400ha (1.92 million feddan) of desert land between 1952 and 1987 and an additional 263.000 ha (627,000 feddan) between 1987 and 1991. During the fifth five-year plan (1993-1997), the reclamation of 240,500 ha (572,700 feddan) was proposed, of which 197,400 ha (469,900 feddan) were actual reclaimed. During the sixth five-year plan (1998-2002), the targeted land reclamation plans were even more ambitious (ICARDA, 2011).

Historically, land reclamation has been the government's greatest agricultural investment, second to irrigation, consuming between 30 and 35% of the agricultural budget. Of the lands reclaimed, significant areas are lost each year through degradation and urbanization. Current reclamation projects seek to cultivate 210,000 ha (500,000 feddan) of desert land through the Toshka project in the southwestern part of the country and 250,000 ha (595,000 feddan) in the eastern part of the Nile Delta and northwestern Sinai (the El-Salam Canal Project).

Although new lands are generally less fertile, their productivity can be improved over time with sound agricultural management practices.

2.4 Key factors affecting newly reclaimed land development processes

The major issues facing Egyptian agriculture are the shortage of water and poor soil characteristics.

Water shortage: the total amount of water used annually from various sources in Egypt is currently about 76 billion m^3. The Nile River directly supplies 70% of this demand and the majority of the rest mostly comes indirectly from the Nile – its groundwater aquifers, reuse of agricultural drainage water, and return flows from the river. By 2017, total water demand is projected to reach about 80 billion m^3/year, while the projected water supply will only reach 76.6 billion m^3/year. This represents a 3.4 billion m^3/year deficiency. The agriculture sector is, and will remain the largest user of water.

Soil characteristics in the desert areas, soil types and their properties are very much influenced by geomorphic and pedogenic factors. Generally, soils in the new lands are short of fertility nutrients (especially micro-nutrients), very low in organic matter, alkaline (high pH), and have inferior physical properties and moisture characteristics. In many areas, other adverse features include a high percentage of calcium carbonate ($CaCO_3$), high salinity content and, in some cases, gypsum. In the main, the physical constraints are hard pans, which are formed at varying depths in the soil profile under the influence of many cementing agents. The characteristics of these resources vary considerably from one location to another because of their mode of formation – mostly wind deposition of varied sediments, and the consequences of terrain attributes.

2.5 Challenges to improving new land development processes

The constraints undermining the attempts to improve the reclamation of new lands include inaccessibility, which impedes communication, prevents the development of infrastructure, and ultimately, increases the costs of transporting inputs and commodities and limits marketing possibilities. Moreover, in areas relying solely on groundwater resources, there are further constraints – limited resources, projected duration of development projects, anticipated changes in the cost of water extraction, and the sustainability of the whole process. Other major requirements include the availability of human resources and certain skills and capabilities.

2.5.1 Technical issues: that could cause difficulties in reclaiming new lands include:

- Lack of appropriate soil texture and composition
- Difficulty in leveling the surface layers
- Absence of organic matter
- Lack of macro-and micro-nutrients
- Shallowness of the soil
- Presence of soluble or less soluble salts, such as CaCO3 and gypsum
- Continual changes in the surface layer as a result of wind movement

- The presence of certain harmful elements, such as boron and selenium, resulting from rock fragmentation.
- Inability to maintain humidity and presence the nutritive elements (sandy soils) or bad drainage (clay soils).

2.5.2 Climate change: An array of serious threats related to the effect of climate change on agriculture is apparent. These threats include:

- Possible effects of sea level rise on the densely populated Nile Delta and coastal areas.
- The likely reduction of the productivity of major crops and increases in their water requirements because of temperature rise.
- A probable general increase in irrigation demand.
- A high degree of uncertainty about the flow of the Nile.

Inefficient on-farm irrigation practices and the irrational use of water will reduce the capacity of Egypt to cope with climate change and potential fluctuation in the Nile's flow. Improved water use efficiency measures, particularly in irrigation, are seen as an essential element of adaptation to climate change and water scarcity. Generally, the main variations in climatic conditions from the Sinai in the north to the Western Desert in the south are annual rainfall, temperature averages, and wind speed and direction. Any increase in aridity towards the southern border will, therefore, cause extreme variations in temperature and very high evapotranspiration. The main factors that can be considered under aridity can be represented by figure (2.3).

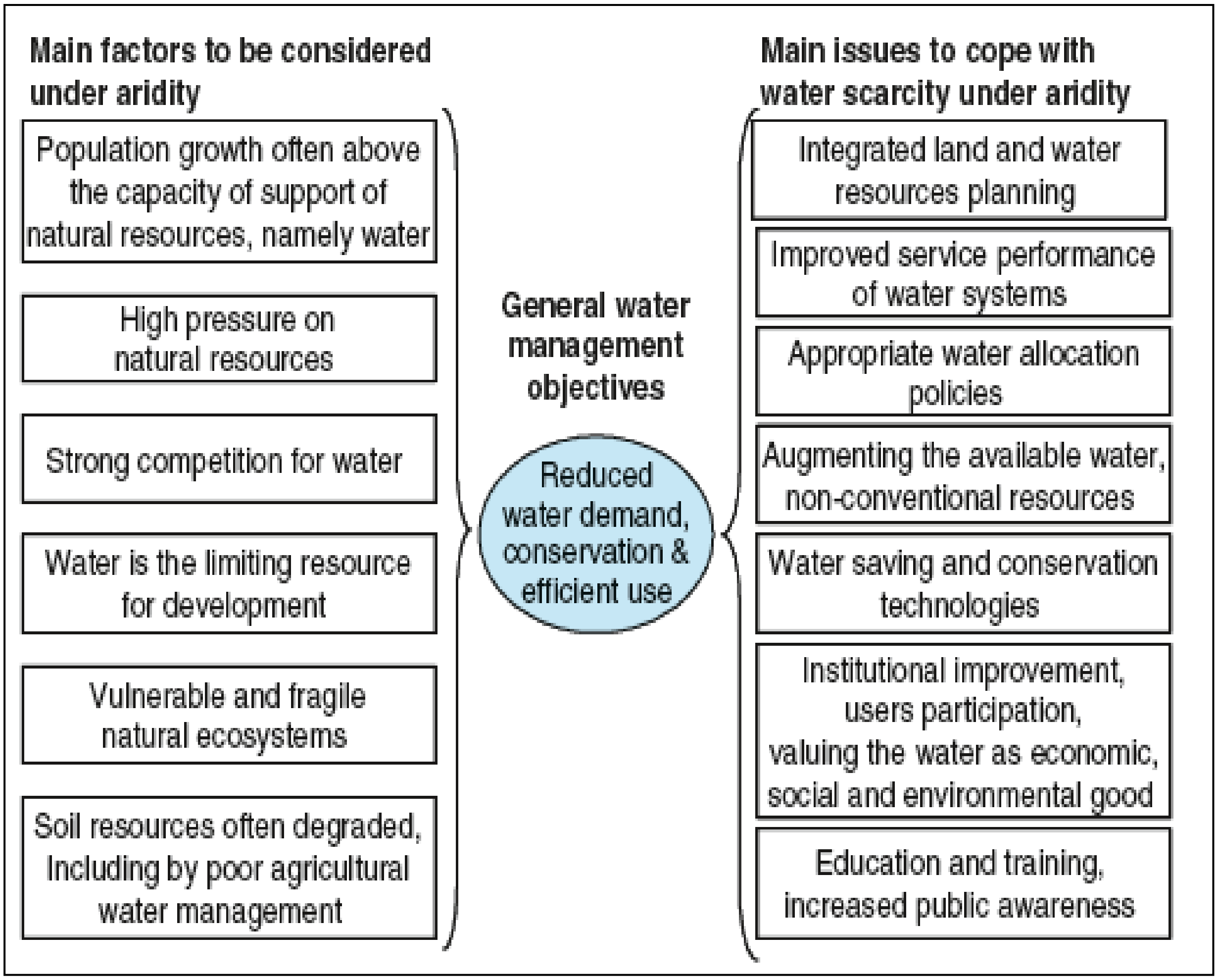

Fig. (2.3) Main factors under aridity

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Chapter 3

Water Resources and Water Allocation in Egypt

Chapter 3

WATER RESOURCES AND WATER ALLOCATION IN EGYPT

3.1 Introduction

The Ministry of Water Resources and Irrigation (MWRI), is working towards the promotion of the integrated water resources management (IWRM) approach. MWRI is the main authority in charge of water resources development, allocation and distribution. Newly developed water resources management strategies have become more integrated in the sense of looking at the water scarcity from all different sides. Current policies of water resources management look at the whole set of technical, institutional, managerial, legal, and operational activities required to plan, develop, operate, and manage the water resources system on both the national and local scales. Not to forget, sustainability is a major objective of all these policies in the sense that the utilization of resources by future generations should not be limited by the use of current generations in any way. Suggested development projects do not necessarily have to serve only one sector. Conversely, by better understanding of the system and better cooperation among all stakeholders, projects can be multi-purpose; e.g. it can serve reclaiming new lands; build new communities and industries, and generating hydropower for these activities while conserving the ecological system for both humans and habitats.

According to Attia, B. 2016, the water resources system consists of the supply system, the demand system, and the management system. The following sections describe briefly the components of each of these sub-systems and analyze the sensitivity of these components to climate variability and change.

3.2 The supply system

Egypt's water resources system is characterized by the complexity and uncertain nature of its many interacting components. Rainfall in Egypt is very scarce except in a narrow band along the northern coastal areas, where an insignificant rain-fed agriculture is practiced. Rainfall occurs in winter in the form of scattered showers along the Mediterranean shoreline. The total amount of rainfall does not exceed 1.5 billion cubic meters (BCM) per year. Flash floods occurring due to short-period heavy storms are considered a source of environmental damage especially in the Red Sea area and southern Sinai.

Egypt receives more than 95% of its various fresh water resources from outside its international borders. The average annual yield of the river is estimated at 84 BCM at Aswan. This yield is subject to wide seasonal variation. Nevertheless, Egypt's annual share of the river water is determined by international agreements by 55.5 BCM. The High Aswan Dam (HAD) is the major regulatory facility on the river. It started its operation in 1968 ensuring Egypt's control over its share of water and guiding its full utilization. Downstream HAD, the Nile water is diverted from the main stream into an intensive network of canals through several types of control structures (7 main barrages along the Nile).

Groundwater is also an important source of fresh water in Egypt both within the Nile system and in the desert. Groundwater in the Nile aquifer cannot be considered an additional source of water as it get its water from percolation losses from irrigated lands and seepage losses from irrigation canals. Therefore, its yield must not be added to the country's water resources but rather be considered as a reservoir in the Nile River system with about 7.5 BCM per year of rechargeable live storage. Groundwater also exists in the non-renewable deep aquifers in the Western Desert region and Sinai with the current total abstraction estimated at only 0.9 BCM per year. On the other hand, most of the available groundwater in the desert is non-renewable and associated with a high development cost. Figure 3.1 shows the quantities of Egypt's water resources.

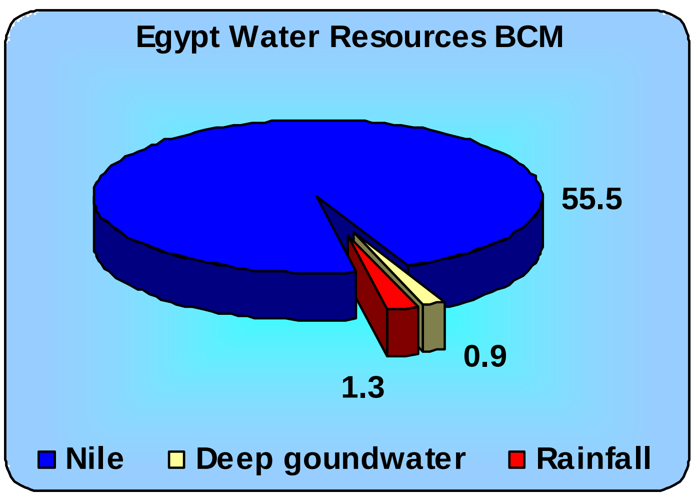

Fig. (3.1)Egypt's Water Resources

Reuse of drainage water in the Nile Delta has been adopted as an official policy since the late seventies. The policy calls for recycling agriculture drainage water by pumping it from main and branch drains and mixing it with fresh water in main and branch canals. There has been a decreasing trend in the amounts of water pumped into the sea with a significant increase in the amounts of drainage water reused recently as the reused quantity amounts to more than 6.5 BCM per year out of total estimated drainage water of 17.5 BCM (year 2013). The reuse of agricultural drainage water and of treated sewage water cannot be considered independent resources. However, they help augment the fresh water supply in certain regions.

This recycling process of the previously used Nile fresh water improves the overall efficiency of the water distribution system. The following sections elaborate the descriptions of each of these resources.

3.2-1The Nile River

Egypt's main and almost exclusive resource of fresh water is the Nile River. The Nile River inside Egypt is completely controlled by the dams at Aswan in addition to a series of barrages between Aswan and Mediterranean Sea. Old Aswan Dam was built in 1902 for annual storage of about 1 BCM. Then increased in 1934 to 5 BCM. For permanent storage the High Aswan Dam (7 kilometer upstream Old Aswan Dam) was completed in 1971, but in 1964, Lake Nasser reservoir, upstream the Dam, started to store water. The Lake total storage is 169.8 BCM with dead storage of 31.4 BCM, active storage of 89.4 BCM, flood control storage of 16.2 BCM, and maximum surcharge storage of 32.8 BCM.

Egypt relies on the available water storage of Lake Nasser to sustain its annual share of water that is fixed at 55.5 BCM annually by agreement with Sudan in 1959. The agreement allocated 18.5 BCM to Sudan annually assuming 10 BCM as evaporation losses from the Lake Nasser each year based on an average annual inflow of 84 BCM/year. This average was estimated as the annual average river inflow during the period 1900 till 1959. Figure3.2 shows the Lake Nasser Storage and the corresponding water levels.

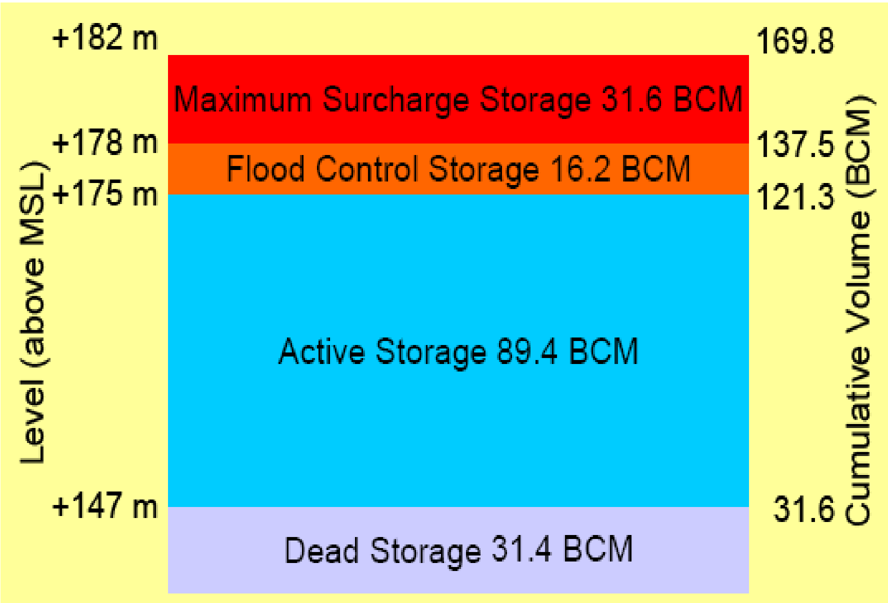

Fig.(3.2): the Lake Nasser Storage

3.2-2 Rainfall over Egypt

Egypt is located at the northern east corner of Africa where the arid climate is prevailing, and classified as the most arid country in the world with an average annual rainfall as low as 51 mm (Aquastat, 2003), which varies from 200 mm in Alexandria at the northern coast, 10 mm in Cairo, and almost zero in the inner areas of the western desert. Rainfall occurs only in winter season in the form of scattered showers (NWRP, 2005). The average annual amount of rainfall water that is effectively utilized is estimated to be around 1.0-1.5 BCM/year. This amount cannot be considered a reliable source of water due to high spatial and temporal variability.

On the other hand, flash floods occurring due to short-period heavy storms are considered a source of environmental damage especially in the Red Sea area and southern Sinai. Flood water velocity depends mainly on the topography of the basin area (height, slope, aspect, drainage network capacity) and its soil type and characteristics. Many studies have been made to determine possible measures to avoid hazards caused by flash floods. Mechanisms have also been developed to harvest flash floods water. This water could be directly used to meet part of the water requirements or it could be used to recharge the shallow groundwater aquifers. It is estimated that about 1 BCM of water on average can be utilized annually by harvesting flash floods.

3.2-3 Groundwater

Groundwater exists in the Western Desert, generally at great depths. Most recent studies have indicated that this is not a renewable resource. Preliminary estimates indicate that the total groundwater storage in this area is of the order of 40,000 BCM, with salinity varying between 200 and 700 ppm. Use of this fossil water depends on the cost of pumping, depletion of storage, and potential economic return over a fixed period. Investigations in the New Valley indicate that about 1 BCM of groundwater can be used annually at an economic rate. This will allow irrigation of 150,000 acres can be irrigated in the East Ewainat area (southern part of the Western Desert) by groundwater from the deep Nubian Sandstone aquifer. More studies are under way to investigate the groundwater potential within this regional aquifer. However current abstraction is estimated to be 2 BCM/year. The main abstracts in utilizing this huge resource are the great depth (up to 15mm) of these aquifers and deteriorating water quality at the increasing depth.

Groundwater is also available in Sinai in numerous aquifers of varying capacities and qualities, but it is generally believed that it is limited in quantity. Shallow aquifers in the northern coastal areas are replenished by the seasonal rainfall especially after heavy storms. The annual rainfall on Sinai varies from 40 mm to 200 mm/year. Most of the rainfall water recharges the shallow groundwater aquifers in northern Sinai such as the delta of Wadi El-Arish and El-Beqaa flood-plain, while such aquifers are absent in southern Sinai. Although most of the shallow aquifers are renewable, only 10 to 20% of the deep aquifers are renewable by rainfall and flash floods. The thickness of the aquifer varies between 30 and 150 m and its salinity increases from 2,000 ppm to 9,000 ppm near the coast. In the northern and central parts of Sinai, groundwater aquifers are formed due to recharge by the rain storms falling and collected in the valleys. Deep aquifers with non renewable water exist in Sinai, where wells are drilled to a depth of 1,000 m to supply water for domestic use. The El-Arish-Rafaa coastal area in north Sinai has always been of importance. The present extraction rate from the Quaternary aquifer in El-Arish is estimated at 52,000 m^3/day. This area is now facing a state of quality deterioration in space and time. The system is being exploited and it needs to be safely managed. The groundwater investigation in South Sinai includes several shallow and deep reservoirs which have a definite potential for development, but again of limited scale.

Shallow Groundwater

The Nile aquifer cannot be considered a separate source of water. The aquifer is recharged only by seepage losses from the Nile, the irrigation canals and drains and percolation losses from irrigated lands. Hence, its yield must not be added to Egypt’s total water resources. Therefore, it is considered as a reservoir in the Nile river system with a huge capacity but with only 7.5 BCM/year rechargeable live storage (MWRI, 2014). The current abstraction from this aquifer is estimated at 6.5 BCM in 2013.

3.2-4 Drainage water re-use

Besides the irrigation network, there is also a huge drainage network, which carries water drained from the agricultural lands and effluents from municipalities and industries. This system starts at field drains then collector drains and main drains which return water directly to the Nile River in Upper Egypt. In the delta, drainage is discharged to costal or inland lakes, or directly to the sea. This delivery is mainly by gravity except for number of pumping stations in North Delta. The amount of water that returns back to drains from irrigated lands is relatively high (about 25 to 30%). This drainage flow comes from three sources; tail end and seepage losses from canals; surface runoff from irrigated fields; and deep percolation from irrigated fields (partially required for salt leaching). None of these sources is independent of the Nile River. The first two sources of drainage water are considered to be fresh water with relatively good quality. The deep percolation component is more salty and even highly saline especially in the northern part of Delta due to seawater intrusion and upward seepage of groundwater to drains. The drainage network carries annual discharge of about 17.5 BCM, from which 6.5 BCM are reused (officially and unofficially) and 11.0 BCM are partly delivered to the sea or lakes. However it is planned to re-use most of this quantity due to water scarcity and leave part of this quantity for salt-balance maintenance.

Reuse of drainage water

Reuse of drainage water in the Nile Delta has been adopted as an official policy since the late seventies. The policy calls for recycling agriculture drainage water by pumping it from main and branch drains and mixing it with fresh water in main and branch canals. There has been a decreasing trend in the amounts of water pumped into the sea with a significant increase in the amounts of drainage water reused recently.

In addition, it is estimated that some 0.65 BCM/year of drainage water is pumped to El-Ibrahimia and Bahr Yousef canals for further reuse. Another 0.235 BCM/year of drainage water is reused in Fayoum while about 0.65 BCM/year of Fayoum drainage is disposed to Lake Qarun. Moreover, drainage pumping stations lift about 0.60 BCM/year of Giza drainage from drains to Rossita Branch just downstream of the delta barrages for further downstream reuse.

Reuse of agricultural drainage water is limited by the salt concentration of the drainage water. Moving from upstream to downstream, the level of salinity increases but in most of the valley and in the southern part of the Delta region, the salinity remains below the critical level of 1,000 ppm which makes it possible for reuse. However, in the northern part of Delta region, large quantities of salt seep through groundwater to the drainage water due to the sea water intrusion. The amount of seawater that discharged into the drains is estimated to be about 2.0 BCM/year. This water is pumped back to the sea and northern lakes to maintain the salt balance of the system. Therefore, more efficient irrigation inevitability leads to the same amount of salt dissolved in a smaller volume of drainage water. That means a more efficient distribution system will result in smaller quantities of reusable drainage water.

Re-use of wastewater

One way of augmenting irrigation water resources is the reuse of treated domestic wastewater being used for irrigation with or without blending with fresh water. The increasing demands for domestic water due to population growth and improvement in the life standards and the growing use of water in the industrial sector due to the future expansion in the Egyptian industry will increase the total amount of wastewater available for reuse. In large cities in Egypt, there are few treatment plants for the collected domestic wastewater.

An agricultural project was implemented to northeast of Cairo to use primary treated wastewater in irrigating about 2500 feddans as early as 1915. Currently, there is a volume of about 1.4 BCM of primary treated wastewater that is being used in irrigation in specific locations outside the Greater Cairo region. It is expected that in the near future this volume of treated wastewater will reach 2.4 BCM by 2017 (NWRP, 2005).

3.2-5 Desalination of sea water

Desalination of seawater in Egypt has been given low priority as a source of water. That is because the cost of treating seawater is high compared with other sources, even the unconventional sources such as drainage reuse. The average cost of desalination of one cubic metre of seawater ranges between 3 to 7L.E. (Egyptian pound). In spite of this, sometimes it is feasible to use this method to provide domestic water especially in remote areas where the cost of constructing pipelines to transfer Nile water is relatively high.

Egypt has about 2400km of shorelines on both the Red Sea and Mediterranean Sea. Therefore, desalination can be used as a sustainable water resource for domestic use in many locations. This is actually practiced in the Red Sea coastal area to supply tourism villages and resorts with adequate domestic water where the economic value of a unit of water is high enough to cover the costs of desalination.

The future use of such resource for other purposes (agriculture and industry) will largely depend on the rate of improvement in the technologies used for desalination and the cost of needed power. If solar and wind energy can be utilized as the source of power, desalination can become economic for other uses. It may be crucial to use such resource in the future if the growth of the demand for water exceeds all other available water resources. Nevertheless, brackish groundwater having a salinity of about 10.000 ppm can be desalinated at a reasonable cost providing a possible potential for desalinated water in agriculture. The amount of desalinated water in Egypt is in the order of 0.03 BCM/year 2010.

3.3 The Demand system

3.3-1 Agriculture

The agricultural sector is the largest user, and consumer, of water in Egypt, with its share exceeding 85% of the total demand for water. Therefore, most land and water policies are mostly concerned with agriculture. The agriculture land base consists of old land in the Nile Valley and Delta, rain fed areas, several oases, and lands reclaimed from the desert. The total irrigated area in 1977 was about 7 million feddans and the rain-fed areas along the Mediterranean coast cover about 0.12 million feddans. Egypt land is generally highly productive. The plan for agricultural horizontal expansion of cultivated land is considered a national plan aiming to increase the agriculture land and crop production. Therefore, cultivated and cropped areas are increasing in the past few years (cultivated area in 1990 was only 6.92 million feddans, while the cropped area was 12.43 million feddans).

The cultivated area in 1995 reached 7.814 million feddans of which 6.204 million feddans in the old lands of the Nile Valley and Delta, and the rest (1.609 million feddans) in newly reclaimed lands. The cropped area reached 13.814 million feddans with 1.77 cropping intensity. In 1996, cultivated area was slightly reduced to 7.56 million feddans, however, the cropped area over 13.5 million feddan resulting from higher cropping intensity of 1.81.

The total area of irrigated land in the year 2000 was approximately 7.7 million feddans (3.25 million hectares) and expected to be 11 million feddans (4.2 million hectares) by the year 2017 due to horizontal expansion and the implementation of the FOUR mega projects of El-Salam Canal at North Sinai and Toshka at south valley and West Delta Conservation and Irrigation Improvement Project and extension of El-Hammam Canal project (NWRP, 2005). Consequently, the agriculture demand is expected to increase from 57.8 to 63.6 BCM taking into consideration the rising of irrigation efficiency by extending the irrigation improvement projects to cover most of the old lands, and applying modern irrigation techniques, e.g., sprinkler and drip irrigation, in the new reclamation lands.

Major crops include wheat, berseem, and vegetables in winter, and maize, rice, cotton, and vegetables in summer, in addition to a little more than million feddans of perennial Fruits. Sugarcane area is maintained around 300,000 feddans, which is a little over the capacity of current sugar factories. The largest consumers of irrigation water are rice and sugarcane because they have high water requirements in addition to occupying a considerable area especially in the case of Rice. Maize, Wheat, and Berseem constitute the next highest water consumers but mainly because they occupy most of the area.

In terms of water use, an important issue is whether the expansion of the New Lands comes at the expense of less water being available for the Old Lands. Productivity per crop is much lower in the New Lands than in the Old Lands. This is expected to improve with time, but initially, newly reclaimed lands do not achieve the yields of the older lands. Expansion into New Lands is considered necessary for agriculture expansion and to accommodate the growing population.

Food self-sufficiency is the ratio between the production and consumption. The present agriculture strategy is not based on self-sufficiency but on food security. Maximizing food self-sufficiency would result in the production of large quantities of basic staple grains, which are relatively low-value in the international market. Egypt is increasingly in a position to produce higher value crops, e.g. fruits and vegetables, and non-food crop, e.g. flax and cotton, and trade them to purchase staples and have additional revenue and employment as well. Maximizing national income is considered a more reliable approach to food security than self-sufficiency.

3.3-2 Industry

Industry is a growing sector in the national economy of Egypt. Further industrial development is expected to play a major role in the socio-economic development of the country, providing employment for a large part of the growing population. Measured in terms of value of public and private industrial output, the petroleum is with 35% the largest, followed by the food industry (24%) the textile industry (13%), and the engineering and electrical industries (13%). The industrial policy is to create new cities and industrial zones outside of the Nile Valley and Delta.

There is no accurate estimate for the current industrial water requirement especially with the new government policy to encourage private sector participation in industrial investment. The private sector contribution to the industrial sector currently exceeds 50% of the total national industrial production where many new industries have been implemented and under production while others still under construction.

In 1990, the general authority for industry made a survey that covered 90% of the public sector major factories to estimate industrial needs and requirements. The study included 321 public sector factories representing the main activities of the industrial sector. The results of the study were used to estimate the water requirement for the industrial sector during the year 2000 where the estimated value was 7.5 BCM/year.

To estimate the industrial water demand for year 2017, it is assumed that the demand of old industries will increase by 20%, and the new industries will increase the industrial area from 102 km^2 in year 2000 to 305 km^2 in year 2017, the design supply is about 7000 m^3/km^2/day. Taking into consideration the increase of demand in mining areas, the total industrial demand may increase from 7.5 BCM in the year 2000 to 8.7 BCM in the year 2017 (NWRP, 2005).

A small portion of the diverted water for industrial requirement is consumed through evaporation during industrial processes while most of that water returns back to the system. Thus, a huge volume of partially treated or untreated effluent is returning to the system creating major environmental problems. A portion of that industrial wastewater goes directly to the sea as in the case of Alexandria's industrial sector.

3.3-3 Municipalities

The supply of sufficient water of good quality is an important element of the national water policy in Egypt. Compared to the agricultural water demand the municipal water demand is small, but given the health aspects involved, this supply will receive priority over all other users. The health aspects are in particular important in the urban centers that will grow as a result of growing population and the increase in urbanization. The government policy with respect to drinking water is to have full coverage of both urban and rural areas including a further improvement of the quality of the services.

Municipal water requirements include water supply for major urban and rural villages. A part of that water comes from the Nile system, either through canals or direct intakes on the river; while the other part comes from groundwater sources. The total municipal water use was estimated to be 4.7 BCM in year 1997. A portion of that water is actually consumed and the rest returns back to the system, either through the sewage collection system or by seepage to the groundwater. There are regions like Alexandria, Suez Canal, and desert areas where the discharge cannot be recovered.

To estimate the increase of municipal (domestic) water demand until year 2017, the increase of per capita income is assumed 4.3% per year, then the annual per capita increase in domestic water demand is taken as 0.1 of the per capita income increase, i.e., 0.43% per year, which is corresponding to an increase of 7.6%

between years 2000 and 2017 (NWRP, 2005). As the population was 68 millions in the year 2000 and expected to reach more than 92millions in the year 2017, then the domestic water demand in 2017 may go up to 130% of the demand of year 2000, i.e., to reach about 7-8 BCM.

This water is delivered to the users through municipal distribution networks in urban areas and few villages. The major factor affecting the amount of diverted water for municipal use is the efficiency of these delivery networks. The studies showed that the average efficiency is as low as 50%, and even less in some areas. The other 50% of the diverted water is lost by leakage from the network. Therefore, the government is paying great attention to the rehabilitation of municipal pipelines networks to improve its efficiency and reduce the conveyance losses. The cost of treating municipal water can be reduced significantly as the efficiency of the distribution network increases.

It is worth mentioning that municipal water requirements include water used to irrigate public gardens and parks. In addition, many small and medium size industries spread in cities and villages use this water for industrial production.

3.3-4 Navigation

The main inland waterway is Nile and few other main canals. Inland waterways are used by traditional sailing boats for the transport of building materials, river barrages and hotel boats. The two Nile branches, Damietta and Rosetta, are planned to be year-round navigable waterways. Major navigation locks are being constructed or rehabilitated. The main navigation activity is the Nile touristic cruises between Aswan and Luxor and the transportation of commodities between Upper and Lower Egypt.

For navigation on the Nile the low flow period from November to February is critical. A safe navigation criterion of water depth is 2.3 m with minimum of 1.45 m. At low water release from Aswan of 75million m^3/day there are about 16 to 18 locations at the Nile and navigation canals with water depth less than the minimum depth required for navigation. There is no exclusive release of water from Lake Nasser for navigation. There is only a guaranteed minimum release of 60million m^3/day for municipal supply. The shallows that affect the navigation will be overcomed through dredging.

Before 1990, water used to be released specifically for navigation purposes during the winter closure period (about 3 weeks in January and February), when the discharges to meet other non-agriculture demands are too low to provide the minimum draft required by ships. Without extra releases from HAD for navigation, ships suffer serious constraints in navigating the Nile during that period especially in Aswan-Luxor reach. The navigation water used to go directly to the sea as fresh water. After changing the winter closer system, there is no excess water for navigation and the above mentioned releases are maintained. Thus, navigation does not consume any water, although it pollutes the water courses.

3.3-5 Hydropower

The total existing hydropower capacity is 2.81 GW, with total annual energy of 12,000 GWH or about 16% of the gross national generated electricity. The High Aswan Dam hydropower capacity is 2.1 GW, i.e. 75% of the total hydropower capacity, while the capacity of Old Aswan Dam, Esna Barrage, and Nag Hammadi Barrage are 22%, 3%, and 0.1% of the total hydropower capacity. Small hydropower stations are still under construction or extension at Al-Lahoon Regulator and Nag Hammadi Barrage and Assuit Barrages. Further possibilities for hydropower development till 2017, with total of 75.5 MW, are being studied.

Because of the increasing of water shortages, hydropower generation has a low priority in water allocation. No releases from High Aswan Dam take place exclusively for hydropower generation. The production of hydropower can be considered to be a by-product of the releases for irrigation, municipal, and industrial water supply and does not need to be taken into account as a separate water demand user. There is no water loss (consumptive use) in the hydropower generation, contrary to the thermal power stations where large amounts of cooling water are lost by evaporation.

3.3-6 Recreation and environmental demands

The aquatic resource base is extensive and includes fresh, brackish, and marine waters. A large part of fish production of the Mediterranean Sea has always depended on the discharge of nutrients from the Nile. This inflow decreased after the construction of High Aswan Dam but was partly compensated by increased drainage of domestic waste nutrients. Increased reuse of drainage water in agriculture results in less drainage to the sea with more decrease in fishing production.

The Northern Delta Lakes are shallow, and have rich aquatic life. Large parts of the lakes are overgrown with aquatic vegetation. The open water area of the lakes are rapidly declined during the last decades due to land reclamation, the formation of in-lake reed islands, and the development of fish farms along the shores of the lakes. The characteristics of the lakes changed considerably. The lakes are fed with agricultural drainage water, mixed with effluents from municipalities and industries. Towards the sea side the salinity increases, but the overall situation of salinity is stable and different aquatic species flourish in different parts of the lakes. The more stable, slightly brackish situation has led to extensive development of aquatic vegetation, providing the species with spawning and nursing, and providing an extended substrate for fish feed organisms. The increase in reuse of drainage water will increase lake water salinity. This is not a problem since good fish production is also possible at higher salinity, and suitable brackish water species are generally of high value. Moreover, higher salinity would provide natural mechanism for weed control.

Feeding northern lakes with drainage water to safeguard aquatic life needs no exclusive release of water from Lake Nasser. On the other hand, a Nile flow of about 240 million m^3/year may be needed to flush water in both Rosetta and Damietta branches to keep acceptable environmental conditions at the end of these branches by allowing the withdrawal of Nile water to sea at these two locations.

3.3-7 Tourism

The number of people visiting Egypt in 2010 reached a record high – more than 14 million tourists spent almost 150 million tourist nights in the country. Tourism is a water-consuming activity because of the need to irrigate golf courses; fill swimming pools, fountains, and artificial lakes; and maintain normal hotel practices. Given that the government hopes to attract 20 million tourists by 2020, the sector will have ever greater water needs.

Furthermore, since the number of ferries commuting on the Nile, especially on the stretch between Luxor and Aswan, has risen to more than 250, these vessels require deeper water compatible with their drafts.

In view of the long distance between the Nile and the summer and winter resorts in the Sinai, Red Sea, and northwestern coast, the conveyance of Nile water has proved to be more expensive than local desalination of sea or brackish water. The amount of desalinated water according to the latest estimates is between 200 and 300 million m3/year, and this type of activity is paid for by investors who charge the same rate to the tourist community.

In summary, the natural resources currently available for use in Egypt are 55.5 BCM/yr and 1.3 BCM/yr effective rainfall on the northern strip of the Delta, now, renewable groundwater for western desert and Sinai, while water requirements for different sectors are in the order of 79.5 BCM/yr. The gap between needs and availability of water is about 20 BCM/yr. This gap is over covered by recycling. The overall efficiency of the Nile system is about 75%.

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Chapter 4

Water Scarcity and Measures for Water Saving

Chapter 4
WATER SCARCITY AND MEASURES FOR WATER SAVING

4.1 Introduction

One of the great challenges facing Egypt is how to use scarce resources in equitable and sustainable way. Water scarcity is now the single greater threat to agriculture development that affects food supply to human health and the environment.

In Egypt more than 85% of the water withdrawal from the Nile is used for irrigated agriculture. Water availability therefore has a direct influence on national food security.

The strategy of the government's plans for sustainable agricultural development and improving new lands processes are dependent on saving water. The following themes are essential for agricultural development:

- Environmentally sustainable management of land and water.
- Rationalizing the use of irrigation water and improving on-farm water management in the old lands.
- Promoting private sector activities in new land reclamation.
- Involving more women in developing processes .
- Improving technology transfer and capacity building activities at the farm level base.

4.2 Water scarcity definition

Wipenny (1997) defined water scarcity as an imbalance of supply and demand under prevailing institutional arrangements and prices, an excess of demand over available supply a high rate of utilization compared with available supply, especially of the remaining supply potential is difficult to tap.

The best-known indicator of water scarcity is per capita renewable water, where threshold values of 500, 1000, 1700m^3/person/year are used to distinguish between different levels of water stress. On this criterion, countries or regions are considered to be: (table 4-1)

- Absolute water scarcity if renewable water resources <500m^3/capita/year
- Chronic water shortage: of renewable water resources are between 500-1000m^3/capita/year.
- Regular water stress between 1000-1700m^3/per capita/year.

Table (4-1) Conventional definitions of levels of water stress (Falkenmark1992).

Annual renewable fresh water (m^3/capita/year)	**Level of water stress**
< 500	Absolute water scarcity
500 – 1000	Chronic water shortage
1000 – 1700	Regular water stress
>1700	Occasional or local water stress

Water Shortage: water supplies are inadequate to meet basic human needs. Measured in terms of per capita supply in relation to a normative basic per capita requirement shortage is absolute, while scarcity is relative scarcity may indicate the prospect of shortage. Various factors and conditions: such as climate change, international conflict, or changes in global food markets can tip scarcity situations into shortage situations.

Drought: Drought is a normal, recurrent feature of climate, an occasional saving of climate to an extreme of its natural variability.

- Drought is a temporary deficiency in rainfall and is conceptually district from variability.
- Drought events vary in terms of severity and duration. Egypt’s last prolonged drought extended from 1980 to 1987.

4.3Types of water scarcity

Winpenny (1997) and the World Bank (2007), suggests considering three types of water scarcity:

- Scarcity of the physical resource
- Organizational scarcity
- Scarcity of accountability

Organizational scarcity refers to “getting water to the right place at the right time”. Accountability refers to governments accountable to their constituencies and services providers to their users.

Three main dimensions of water scarcity that can be summarized as follows:

- Scarcity in availability of water of acceptable quality with respect to aggregated demand, in the simple case of physical water shortage.
- Scarcity due to the lack of adequate infrastructure respective of the level of water resources, because of financial, technical or other constraints.
- Scarcity in access to water services, because of the failure of institutions in place to ensure reliable, secure supply of water to users.

4.4 Concept of water scarcity

The concept of scarcity also embraces the quality of water because degraded water resources are unavailable or at best only marginally available for use in human and natural system . Figure (4-1) illustrates the causes for water scarcity, which may be natural, dominated by climate change or man-made. Pollution and contamination degrade the water quality and led to water unavailability for many uses.

Demand may grow much in excess of availability. In other words, natural scarcity may be aggravated by human influences, such as population growth and poor water management. Main-made water scarcity is a consequence of these and other human activities.

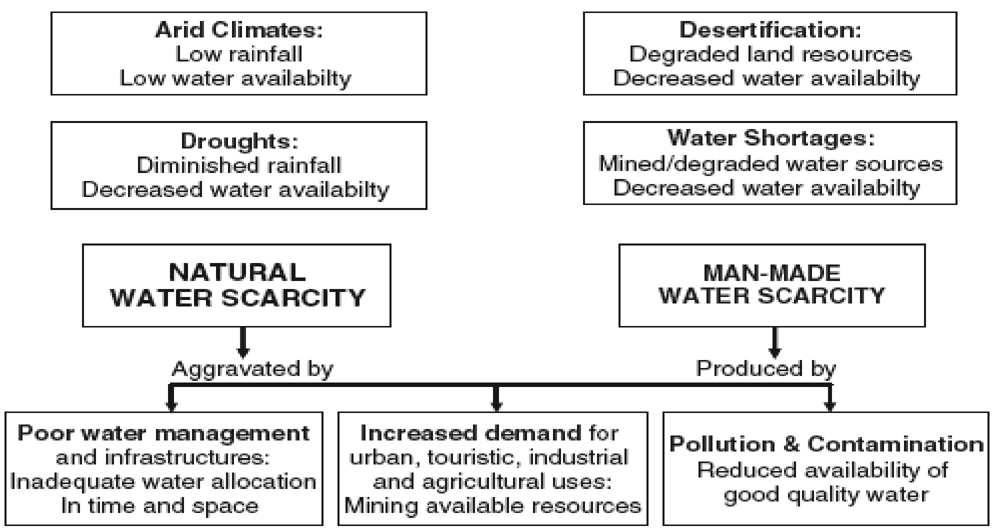


Fig. (4.1) Natural and man-made water scarcity.

In brief water scarcity causes may be:

- Climate change
- Growth of population and incomes
- Modifications in land scape and land use e.g.

- Urbanization leading to increased runoff
- Desertification
- Silting reservoirs

Water diversion to new lands:

- Water pollution
- Failure to manage demand
- Finance

Financial: institutional short comings in water systems management

4.5 Water issues and considerations

Egypt has reached a state where the quantity of water available is imposing limits on its national economic developments. As indication of scarcity in absolute terms often the threshold value of 1000m^3/capita/year. Of absolute scarcity, 500m^3/capita/year is used; this will be evident with population predictions for 2025 which will bring Egypt down to 500 m^3/capita/year.

The total population of Egypt increased from 22 million in 1950 to around 92 million in 2016. The annual rate of population growth has reached almost 2%.

This rapid growth in population will continue to increase between 120-150 million by 2050. This high population growth rates will exaggerate the problems associated with water sector allocation.

Agriculture consumes the largest amount of the available water in Egypt, with its share exceeding 85% of the total demand for water. In view of the expected increase in demand from other sectors, such as municipal and industrial water supply, the development of Egypt's economy strongly depends on its ability to conserve and manage water resources.

From the other hand, the Nile River is very sensitive to temperature and precipitation changes mainly because of its low runoff/rainfall ratio (4%). The prolonged 1980-1987 drought forced Egypt to reduce its water use despite the inter-annual storage in Lake Nasser behind the High Aswan Dam, which clearly shows the vulnerability of Egypt to changes in river flows that climate change may produce. As climate change prediction model identified water resources as one of the three vulnerable sectors to climate change; the others being coastal zones and agricultural resources

Egypt is affected by climate changes impacts within the whole Nile basin, which it shares with 10 other countries. Economic developments in these countries will put more pressure on water resources in Egypt.

4.5-1 Water uses and available resources

a. Water status in year 2000

As indicated by Allam and Allam. 2007, table (4-2) shows that in year 2000, there was a balance between water uses and available resources. To evaluate the efficiency of the irrigation water system, fig. (4.2) shows a simplified diagram of the system. As shown in the figure the total losses of the water system, evaporation and outflow, were about 13.25 BCM.

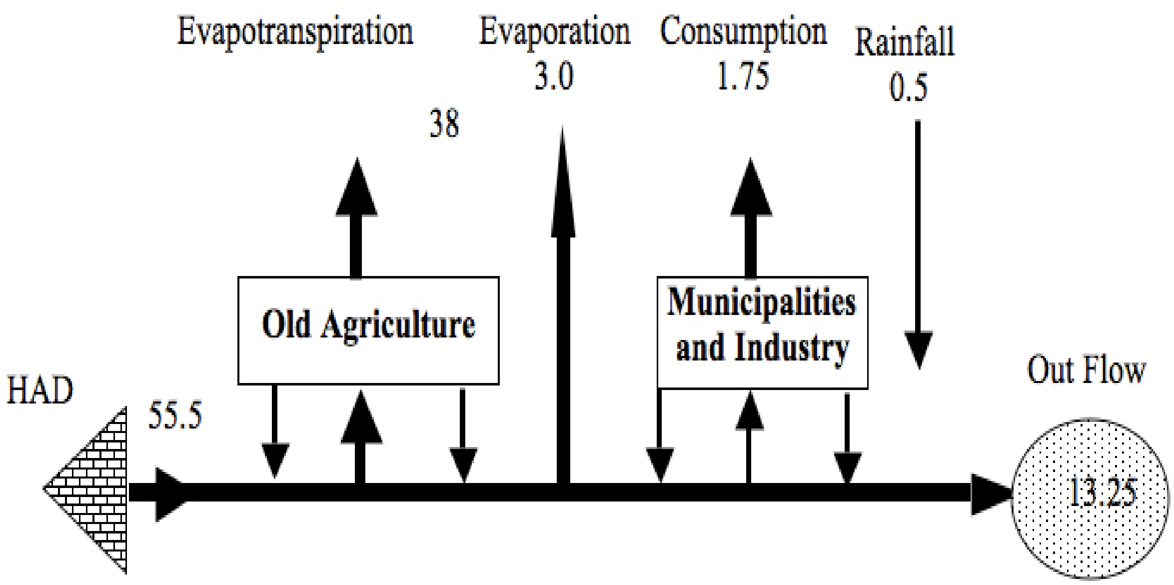


Fig. (4.2)**Water Status in Year 2000** (Allam and Allam 2007)

The losses were 29% of the network annual inflow. Water consumption was about 59.75 BCM/year divided between agriculture (38 BCM), municipalities and industry (1.75 BCM). The overall efficiency of the water system in the year 2000, which equals the consumption as a percentage of the total influence, was about 71%.

Table (4-2) Water Resources in Egypt (year 2000)*

Water Uses (BCM/year)		Water Resources (BCM/year)	
Sector	**Amount**	**Resource**	**Amount**
Municipalities	5.25	Nile river	55.50
Industry	3.50	Groundwater (Delta & Valley)	5.50
River transport	0.25	Deep groundwater	0.8
Fisheries	--	Drainage water reuse	
Hydropower	--	– Canals in the Delta regions	4.5
Agriculture	63.00	– Nile river and Bahr Yousef	5.0
		– Illegal uses	3.0
		Waste water reuse	0.2
		Rainfall and flash floods	0.5
		Evaporation losses	(3)
Total	**72.00**	**Total**	**72.00**

**(Allam and Allam 2007)*

b. Water status in the year 2014

The actual resources available for use in Egypt are 55.5 BCM/year and 1.3 BCM/year effective rainfall on the northern strip of the Delta, non-renewable-groundwater for western desert and Sinai (2 BCM).

Table (4-3) shows in detail, the available water resources and water uses for the year 2014. From this table, the water requirements for different sectors are in the order of 81.05BCM /year.

The gap between the needs and availability of water is about (17-20) BCM /year. This gap is over come by recycling and reuse and desalination.

Table (4-3) Available water resources and water uses (year 2014)

Water Resources (BCM/year)	**Amount**	**Water uses (BCM/year)**	**Amount**
Nile River	55.5	Municipalities	10.0
Groundwater (Delta and Valley)	6.50	Industry	3.00
Deep Groundwater	2.0	Agriculture	63.80
Drainage water-reuse	15.25		
From the Delta	7.0	River transport	0.25
From Nile River	4	Fisheries	1.00
From Bahr Yossif (Fayoum)	1.20	Evaporation	3.00
Illegal Uses	3.00		
Rainfall and Flash Floods	1.3		
Waste water re-use	0.3		
Desalination	0.20		
TOTAL	81.05	TOTAL	81.05

4.5-2Water shortage

The water shortage is the main constraint and a major limiting factor facing the implementation of the country's future economic developments plan.

In addition to the fixed Nile Quote of (55.5) billion cubic BCM, a deep ground water resources which is not renewable may be utilized mater with a rate of 3.0 BCM/year uses period of 100 years (Nubian sand stone aquifer) and it is also possible to utilize rate of another3,BCM from both fishered sandstone aquifer and Moghra aquifer.

The total amount of water used annually from various sources in Egypt is currently about 78.4 billion m^3. The Nile River directly supplies 70% of the demand and the majority of the rest mostly comes indirectly from the groundwater aquifers, re-use of agricultural drainage water, and return flows from the river.

By the year 2020, the total demand is projected to increase by 20% i.e. about 94.00 billion m^3/year, while the projected water supply will reach 78.4 million m^3/year. This represents a 6.00 billion m^3/year deficiency. The agriculture sector is, and will remain the largest user of water.

4.5-3 Water pollution

With the steady increase of population and the continuous expansion of urbanized areas, pollution issues have increased too. Water quality has a direct effect on the quantity available for a specific use. As the quality of water gets worse, its scope of use narrows thereby, reducing supplies and intensifying shortages. Thus the determination of quality will increase the severity of the scarcity.

4.5-4 Climate change

An array of serious threats related to the effect of climate change on agriculture is apparent. These threats include:

- Effects of sea level rise on the densely populated Nile Delta and coastal areas.
- The likely reduction of the productivity of major crops and increase in this water requirement because of temperature rise.
- A probable general increase in irrigation demand.
- A high degree of uncertainty, about the flow of the Nile.
- Inefficient on-farm irrigation practices and the national use of water will reduce the capacity to cope with climate change and potential fluctuation in the Nile's flow.

Generally the main variations in climate conditions are around rainfall, temperature averages, and wind speed and direction. Any increase in aridity will therefore, cause extreme variations in temperature and very high evaporation.

4.6 Water scarcity management

Several ways to classify scarcity management measures, these are:

4.6-1 Supply management

Water scarcity can be addressed by supply augmentation (supply measures) or by measures which reduce the per capita burden on the existing supply (demand measures).

Supply augmentation measures applicable include:

- River water capture and storage.
- Surface water capture and storage.
- Increased abstraction from existing groundwater sources.
- Deep mining of groundwater with large scale water transfer.
- Desalination.
- Increasing share of Nile basin waters.
- Virtual water impact.

4.6-2 Demand management

Demand management covers a wide range of measures such as (fig. 4.3) e.g.

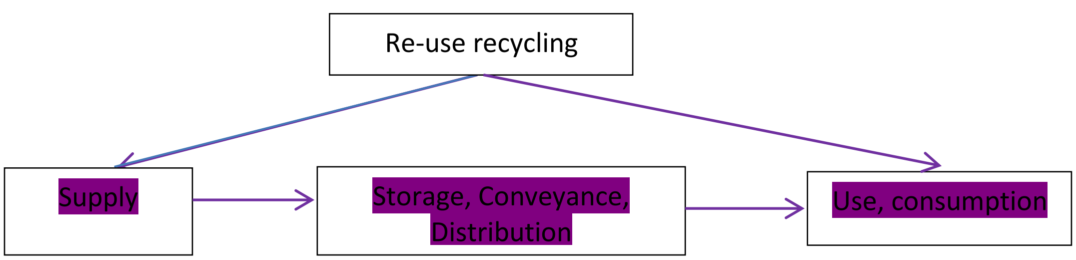


Fig. (4.3) simplified water cycle

- Distribution efficiency measures: water loss reduction (agriculture, municipal, industrial).
- Consumption-related measures: measures which promotes reduction in end wastage or consumption.
- Re-use measures: Re-use effectively expands:

Supply by returning once-used water to the system for a second use. It may be direct (wastewater irrigation) or indirect (ground water – recharge).

These measures need to be carefully analyzed and planned to avoid unintended consequences which might exacerbate scarcity.

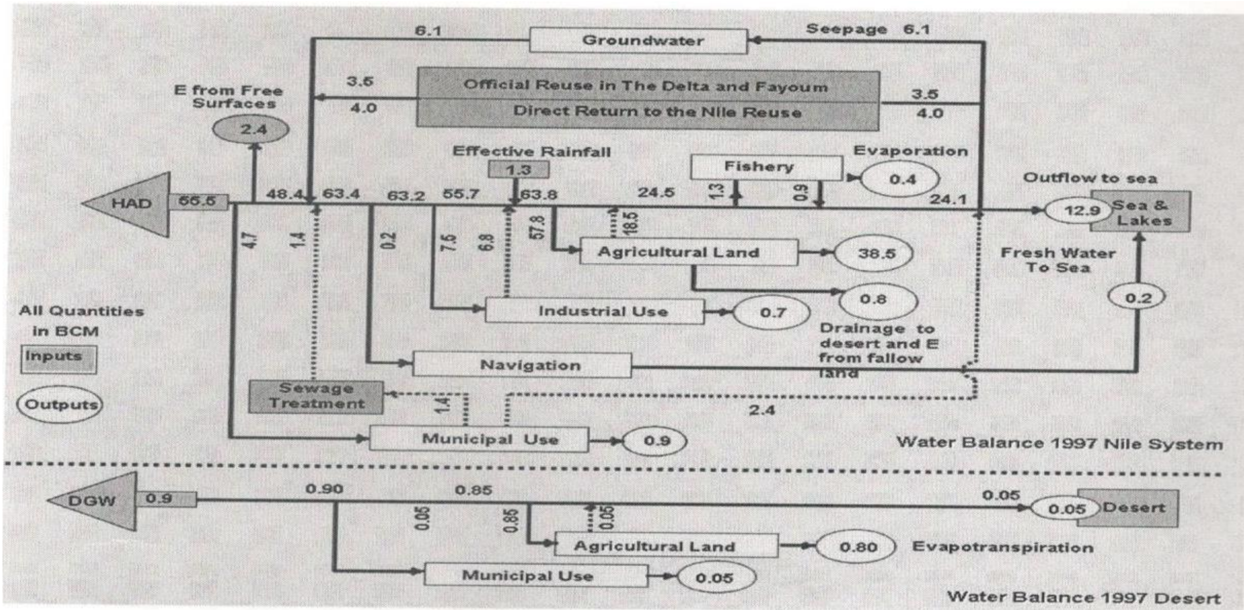
4.6-3 Supply and demand projection (App 2007)

Table (4-4) shows Egypt's year 1997 water balance. "Evapotranspiration" is synonymous with consumptive agricultural use, i.e., water consumed in food production. Note that the Nile System flow chart shows that the supply (55.5 BCM) is "supplemented" by groundwater (6.1 BCM), return flows from all uses (6.5 BCM), and rainfall (1.3 BCM). The "outputs" (terminal outflows) listed in the table correspond to the figures contained in the circles in the flow chart.

Table (4-5) shows the projected 2017 water balance. It is important to note that there is no increase in HAD supply levels and that rainfall levels are assumed to be the same as in 1997. Yet population is expected to increase by nearly 20 million and the irrigated area is expected to increase from 7.9 million feddans (1997) to 10.3 million feddans (in 2017). This would entail a decline in water consumption per feddan from 4,800 m^3 to 3.400 m^3. Moreover the flow chart shows increased allocations for municipal, industrial and agricultural use.

How is the challenge of meeting an expanding demand from a fixed supply to be met? Leaving aside the increased withdrawals from groundwater in the Desert (which is not hydrologically commented to the Nile System) and a slight increase in Nile groundwater withdrawals (from 6.1 BCM to 6.4 BCM), the flow chart indicates that the great majority of new demand is expected to be met primarily through:

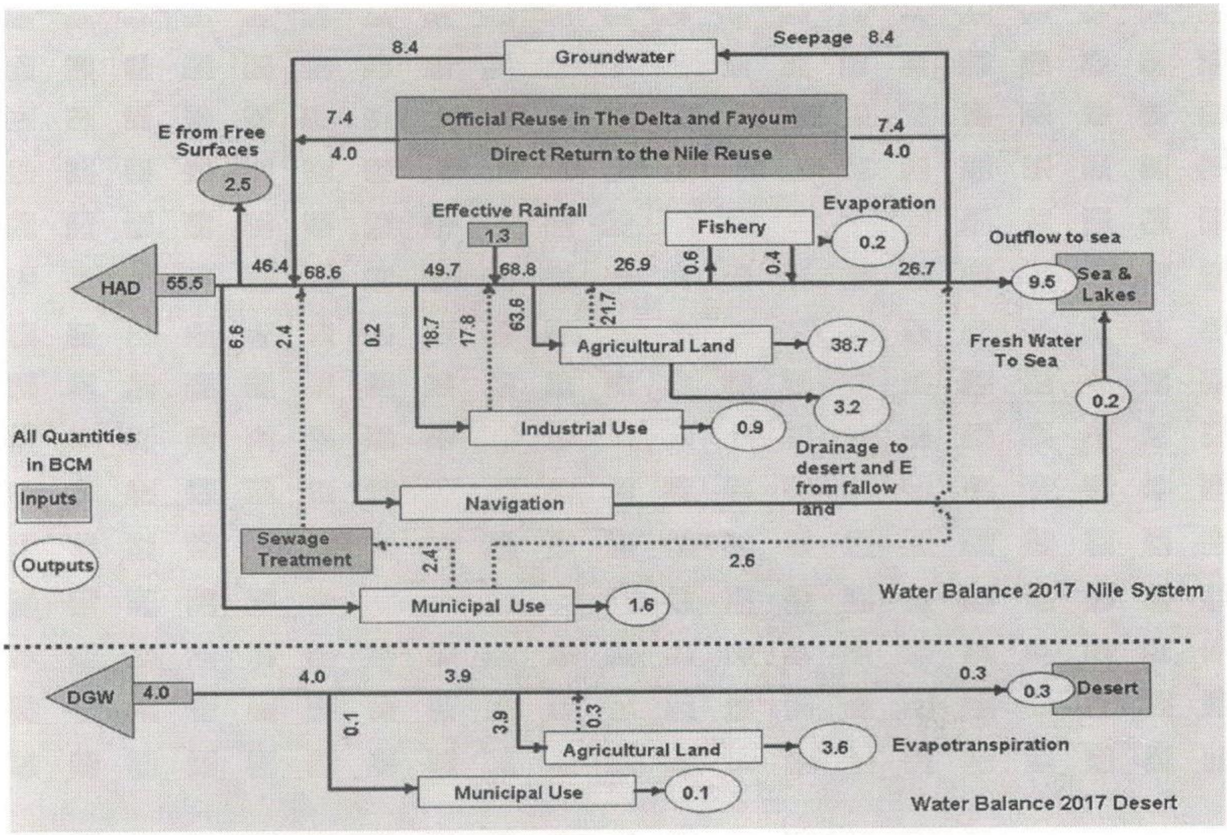
a. Vastly expanded reuse of municipal, industrial, and agricultural water (indicated by the reduction in terminal drainage water outflow from 12.9 BCM to 9.5 BCM and in municipal and industrial outflows from 2.5 BCM to 1.6 BCM).
b. Increased agricultural water use efficiency (indicated by the steady evapotranspiration outflow in spite of the increased agricultural water allocation).



Inputs	BCM	Outputs	BCM
1. Surface water			
Nile water	55.5	Desert, Qaroun lake	0.65
Rainfall	1.3	Fresh water to sea and north lakes	0.20
		Drainage water including fisheries	12.90
		Open surface evaporation	2.40
		Evaporation from fallow lands	0.15
		Fish ponds	0.40
		Municipal and industrial consumption	1.60
		Evapotranspiration	38.5
Total	**56.8**	**Total**	**56.8**
2. Deep Groundwater			
Deep GW	0.9	Evapotranspiration	0.80
		Municipal use	0.05
		To desert	0.05
Total	**0.9**	**Total**	**0.9**

(Source: National Water Resources Plan 2017, MWRI, 2005)

Table (4-4) Water Balance for the year 1997 based on consumption



Inputs	BCM	Outputs	BCM
1. Surface water			
Nile water	55.5	Desert, Qaroun lake	2.70
Rainfall	1.3	Fresh water to sea and north lakes	0.20
		Drainage water including fisheries	9.50
		Open surface evaporation	2.50
		Evaporation from fallow lands	0.50
		Fish ponds	0.20
		Municipal and industrial consumption	2.50
		Evapotranspiration	38.7
Total	**56.8**	**Total**	**56.8**
2. Deep Groundwater			
Deep GW	4.0	Evapotranspiration	3.60
		Municipal use	0.10
		To desert	0.30
Total	**4.0**	**Total**	**4.0**

(Source: National Water Resources Plan 2017, MWRI, 2005)

Table (4-5) Water Balance for the year 2017 based on consumption

4.7 Water scarcity management measures

It is important to note that MWRI's 2017 water balance supply and demand management measures are listed in table (4-6).

Table (4-6) measures for meeting 2017 water demand

Measure
Additional pumping from renewable groundwater sources in the Delta and Valley
Abstraction from new renewable groundwater sources in the desert
Harvesting flashfloodsin the valley and rain in the Delta
Increasing agricultural drainage re-use
Re-use of treated municipal wastewater
Water saving by reducing sugar cane area and by applying improved irrigation techniques
Water saving by irrigation improvements projects
Water saving by reducing rice area and using early maturing rice variations.
Water saving by up grading the irrigation network.

Major measures under consideration for (2017-2030) include:

- Deep mining of non-renewable groundwater
- Desalination
- Biotechnology applications to agriculture
- International cooperative Nile Basin projects
- Water pricing/cost recovery.

In view of the impacts of delay in achieving the measures listed in table (4-6) and the risk of drought or accelerated climate change, it may be worthwhile for policy-makers to consider these measures which aim to promote efficiency and conservation by water users. It should be kept in mind that the MWRI's three hold classification of water management strategies in which:

- Developing additional resources
- Making better use of existing resources
- Protecting water quality.

The MWRI's water accounts (i.e. the water balance from 1997 to 2017) show that since 1997 Egypt has entered the era of water scarcity, i.e. has reached the limits if its ability to supply increasing amounts of its ability to supply increasing amounts of water per capita. Policies, laws, and institutions have to change of water is to be valued and demand is to be managed.

Water scarcity is a matter of national concern not the concern of only two ministers. Water efficiency and conservation need to be strategies objectives of all ministries. This may have effects on their policies objectives and programs.

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Chapter 5

Water Saving in Irrigated Agriculture

Chapter 5

WATER SAVING IN IRRIGATED AGRICULTURE

5-1 Introduction

The importance of saving water in irrigation

Irrigation is the main water consumer in water scarce region. Demand for irrigation largely exceeds that of all other user sectors which makes water conservation and saving in irrigation to the vital importance. Demand management in irrigation, or water conservation and saving, refers essentially to two domains: (1) appropriate selection and use of the irrigation systems and (2) the adoption of irrigation scheduling strategies. The both allow the satisfaction of the crop water requirements when minimizing water use and at the same time maximizing crop profit under the constraints of water scarcity.

There is a common idea that has unfortunately spread everywhere-that surface irrigation is highly inefficient and water consuming and thus should be replaced by modern methods such as sprinkler and drip irrigation. Proponents have ignored some facts: surface irrigation has supported sustainable farming in water scarce regions for centuries or millennia and users developed local management and engineering skills that adapted the irrigation technologies to solve the dominant problems.

In some areas surface irrigation has been replaced by sprinkling or drip due to economic and managerial reasons. Another common idea is that drip irrigation is the only irrigation system that provides for effective water saving. Unfortunately, this is not true. For drip irrigation to produce water saving and conservation it is necessary that the irrigation systems are well designed and operated, equipment is selected that is appropriate for the crops, the soil, water quality and environmental conditions, and that equipment for the crops, is adequate for maintenance.

Unfortunately drip systems are being sold by shops and people without qualifications, farmers never receive adequate instructions, such as that a filter is required or it must be cleaned. In many of these circumstances farmers use more water with drippers than they would with surface irrigation. Drip irrigation is often inappropriately used in sandy soils, where drip bulbs are narrow and water easy infiltrates below the roots, producing rapid contamination of the groundwater while keeping the crops stressed and low yielding.

Irrigation scheduling is another area of concern. It is well known that crop responses to irrigation water depend upon the timelines of water application. Farmers have always known this and developed appropriate skills to irrigate their common crops within the constraints of their soils and climate as well as the irrigation systems they use.

Coping with water scarcity is developed to show that efficient water use may be adopted for surface, sprinkler or drip irrigation or through appropriate irrigation scheduling. A variety of technological solutions have become available.

There are tools available for demand management that may apply to every condition. However, there is a need for upgrading of the knowledge and skills of engineers, agronomists, managers and policy and decision makers to provide conditions for their effective application. There is also the need for effective, available advisory services, improvement of markets, training and capacity building incentives and credit facilities.

5.2 Demand Management: general aspects

Demand management for irrigation to cope with water scarcity consists of reducing crop irrigation water requirements, adopting irrigation practices that lead to high irrigation performance and water saving, controlling system water losses and increasing yields and income per unit of water used. It includes practices and management decision of an agronomic, economic, and engineering nature. The objectives of irrigation demand management can be summarized as follows:

Reduced Water Demand: through selection of low demand crop varieties or crop patterns, and adopting deficit irrigation, i.e. deliberately allowing crop stress due to under-irrigation, which is essentially an agronomic and economic decision.

Water Saving Conservation, mainly by improving the irrigation systems, particularly the uniformity of water distribution and the application efficiency, reuse of water spills and runoff return flows, controlling evaporation from soil, and adopting soil management practices appropriate for augmenting the soil water reserve, which are technical considerations.

Higher Yields per Unit of water, which requirement adopting best farming practices, i.e. practices well adapted to the prevailing environmental conditions, and avoiding crop stress at critical periods. Improvements in water productivity result from a combination of agronomic and irrigation practices.
Higher Farmer Income: which implies to farm high products, and to select cash crops. This improvement is related to economic decisions and market opportunities.

Issues for irrigation demand management often refer only to irrigation scheduling, giving to irrigation methods a minor role. However, an integrated approach is required (Pereira 2009, 2002b). Irrigation scheduling is the farmers decision process relative to "when" to irrigate and "how much" water to apply at each irrigation. The irrigation method concerns "how that desired water depth is applied to the field. The crop growth phase, its sensitivity to water stress, the climatic demand by the atmosphere, and the water availability in the soil determine when to apply irrigation or, in other words, the frequency of irrigation. However, this frequency depends upon the irrigation method, i.e. on the water depths that are typically associated with the on-farm irrigation system. Therefore, both the irrigation methods and the irrigation scheduling are inter-related.

Several performance indicators are currently used in on-farm irrigation. The uniform of water application to the entire field is commonly evaluated through the distribution uniformity (DU), which is the ratio between the average infiltrated water depth (mm) in the low quarter of the field and the average infiltrated water depth (mm) in the entire field (Burt et al. 1997, Pereira 2009). The distribution uniformity essentially depends upon the characteristics of the irrigation system and only to a small degree on farmer management. In other words, high DU can only be achieved when the farmers manage the irrigation system well and it is well designed and maintained, whilst poorly designed and/or maintained irrigation systems will almost always lead to low DU (Pereira et.al. 2002b).

The main farm efficiency indicator is the application efficiency (AE), the ratio between the average water depth (mm) added to root zone storage and the average depth (mm) of water applied to the field. AE is a measure of the quality of irrigation management by the farmer and is strongly related to the appropriateness of decisions on when and how much water is applied. Due to the limitations imposed by the system characteristics, the application efficiency depends upon the distribution uniformity.

5.3 Demand Management (others)

- **Improving Surface Irrigation**

Several surface irrigation methods are used in practices. The main ones are basin, furrows, and border irrigation.

Basin Irrigation: which is the most commonly used irrigation system. Basins must be precisely leveled for uniform water distribution, because basin topography determines the recession, or removal from the surface, of the ponded water.

Furrow Irrigation: Furrow irrigation is primarily used for row crops. Irrigation furrows are usually directed along the slope of the field.

Border Irrigation: water is applied to short or long strips of land, diked on both sides and open at the downstream end. Border irrigation is used primarily for close growing crops such as small grains, pastures and folder crops and for orchards and vineyards.

Improvements in surface irrigation systems that help to cope with scarcity are numerous and depend upon actual field conditions (Pereira LS, 2009). Improvement aimed at reducing the water volumes and increasing the water productivity to cope with water scarcity which can be grouped as follows:

a) Land leveling: is very important practice to improve surface irrigation performance.

b) Irrigation with anticipated cut-off-i.e. cutting the inflow to basins before the advance is completed, or to furrows before the downstream area is irrigated.

c) Improved design and modeling. This is through the selection of best combination of field sizes, slope, inflow discharges and time of application that optimize conditions for controlling deep percolation, runoff, leaching fraction applications, and deficit irrigation.

d) Paddy rice irrigation replacing permanent basin flooding by temporary, inter mitten flooding where the soil water is maintained near saturation for most of the time. Water saving may be achieved by maintaining low water depths, because seepage and percolation are then controlled.

e) Improvements in furrow and border irrigation, including:
   - Irrigation with alternate furrow to reduce water application to the entire field and favoring deep rooting of the crops.
   - Closed furrows to avoid tail end runoff. Re-use provides for water saving that may be as high as 40% of the applied volumes
   - Surge flow, i.e. intermittent, cycling of water application to furrows. Surging usually requires system automation.

f) Water efficient systems to deliver water to basins, furrows.
   - Gated pipes and lay flat tubes to convey and deliver the water to basins, furrows.
   - Buried pipes provide easy control of applied discharges, reduced seepage and avoid runoff.
   - Lined farm distribution canals permit good control of discharges applied when siphons are used.
   - Automation and remote control of farm systems can improve operations, mainly by applying improved irrigation scheduling.
   - Improving surface irrigation. Systems require not only knowledge and technology but economic feasibility.

5.4 Irrigation Water Quality and Land Productivity

Agricultural activities and associated drainage network contribute to water quality determination in Egypt. Covering the whole Nile Valley and Delta, the drainage network discharges wastes into the Nile mainstream and the northern lakes and sea and coast. This irrigation misconduct affects water quality through three channels: changing salinity level, adding chemical fertilizers and pesticides to irrigation water and eutrophication of water bodies. The various pollution loads led to significant water quality degradation table (5-1).

Table (5-1) recycled drainage water in the Nile Delta 2000/2001 (BCM per annum)

Salinity level p.p.m	East Delta	Middle Delta	West Delta	Delta
<750	0.664	0.085	0.575	1.324
750-1000	0.422	0.458	0	0.88
1000-1500	0	1.416	0.067	1.483
1500-2000	0.755	0	0	0.744
2000-3000	0	0	0.416	0.416
Total	1.83	1.959	1.058	4.847

Source: Drainage Research Institute (2004).

In Egypt, perhaps the most critical factor in predicting managing, and reducing salt-affected soil is the quality of irrigation water being used (the main sources of the salinity in the Delta soils are irrigation water, mediterranean saline water and the high level water table). Besides affecting crop yield and soil physical conditions, irrigation water quality can affect fertility needs, irrigation system performance and longevity, and how the water can be applied. Therefore, knowledge of irrigation water quality is critical to understanding what management changes are necessary for long-term productivity. Table (5-2) provides quantitative estimations for potential yield reductions due to increases in salinity level of irrigation water.

Table (5-2) potential yield reduction from saline water

Crop	Yield Reduction (%)			
	0%	10%	25%	50%
	EC_w			
Barely	0.3	6.7	8.7	12
Wheat	4	4.9	6.4	8.7
Sugar beet	4.7	5.8	7.5	10
Alfalfa	1.3	2.2	3.6	5.9
Potato	1.1	1.7	2.5	3.9
Corn (grain)	1.1	1.7	2.5	3.9
Corn (Silage)	1.2	2.1	3.5	5.7
Onion	0.8	1.2	1.8	2.9
Dry Beans	0.7	1	1.5	2.4

EC_W: electric conductivity of water

5.5 Water Saving Challenges

Egypt among the developing countries have different characteristics features as regards the water resources development and management and so also the issues and challenges.

Egypt is facing major constraints with respect to its water resources. These may be stated as follows:

- A fixed surface water supply (Egypt's quota of 55.5 billion m^3/year) discharged from outside through River Nile. This quota which is a critical factor affects production, services and sustainable development and constitutes 90% of the country water budget, the remaining 10% represents minor quantities of renewable and fossil groundwater and a few showers of rainfall.
- Nile is the main source of fresh water in Egypt, within share of more than 95%. The storage reservoir of Nasser Lake provides 55.5 billion BCM/years. The issue of Egypt's share of Nile waters is under difficult negotiations. In April 2011, Ethiopia has launched the construction of the Grand Ethiopian Remainance Dam, GERD, (known later as Sadd El-Nahda), with water storage of 74 BCM and Energy generation of 6000 MW. It is one of the largest water reservoirs in the continent. Egyptian experts give indication of 20-34% reduction when the filling period overcuts the drought periods. This is estimated to be (11-20) BCM on average over the Dam's filling period.

- **Population growth** and the essential need for horizontal expansion of cultivated land, which is vital to feed Egypt's growing population and ensure social and political stability will increase demand for irrigation water. Egypt's population grew from 38 million in 1977 to 90 million in 2015. The annual growth rate in recent years is about 2%.The population is expected to reach to 92 million by 2017 of all the sectors, agriculture is the largest consumer of water, representing about 85% of the total water demand. The country as a whole are, experiencing severe water scarcity. In 2006 the per capita share of water was 850 m^3/year, five years later in 2011 this figure had decreased to 700 m^3/year and it is expected to drop to 500 m^3/day by 2030. This figure is widely considered to be below the water poverty level. (1000 m^3/year/person).

- **Climate change**: an array of serious threats to the effect of climate change on agriculture is apparent. These threats include:
  - The likely reduction of the poor productivity of major crops and increases in their water requirements because of temperature rise.

- A probable general increase in irrigation demand.
- A high degree of uncertainty about the flows of the Nile.
- Possible effects of sea level rise on the densely populated Nile Delta and coastal areas.
- In efficient on-farm irrigation practices and the national use of water will reduce the capacity to cope with the water requirements and climate change.
- Improved water use efficiency and water saving measure, particularly in irrigation management for different crops are essential element of adaptation to climate change and water scarcity.

Generally the issues and challenges for water saving may be summarized as follows:

- Poor infrastructures,
- Need for rehabilitation of old systems
- Low irrigation efficiencies,
- Negligible re-use and use of poor quality waters for irrigation
- Use of traditional/conventional irrigation methods.
- Environmental sustainability.
- Very low public awareness in water saving.

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Chapter 6

Cropping Pattern Changes for Water Saving

Chapter 6
CROPPING PATTERN CHANGES FOR WATER SAVING

6.1 Introduction

The agriculture sector plays a central role in the Egyptian economy, contributing by 14% to GDP (2010) and it is the largest absorber of employment as it accounts for more than 30% of the work force. Throughout the past five decades, the Egyptian Agriculture sector was subject to major policy changes that had substantial impact as this sector, and that had greatly caused major shifts in the cropping pattern. As the water scarcity is considered a major limitation for the expansion of agricultural sector, an efficient crop pattern should be shaped or changed to minimize the amount of consumed water and save it.

Since the beginning of the last century, crop pattern in Egypt have been composed of six major crops, namely cotton, maize, wheat, rice, clover and sugarcane. Crop intensification ratio under this pattern is 172%. This ratio should be increased to 200% to face the increasing percentage of population in Egypt, as it is expected that it will reach 125 million inhabitants in 2030.

This study deals with setting up the scenarios for the best possible cropping pattern with less water consumption. These scenarios are cultivation on raised beds and/or intercropping of important crops on other crops, in addition to cultivation of three crops per year. Crop water productivity with the cropping under Agro-climatic zones and the suggested cropping pattern under Egyptian sustainable agriculture development strategy 2017-2030.

6.2 The Egyptian Agriculture

Egyptian agriculture possesses certain features that make it unique among other agricultural systems all over the world. Such uniqueness is the outcome of the combined effects of these features. The Old Lands in the Nile valley are the main growing areas in Egypt that are characterized by complex-year long cropping pattern. The richest crop production area is the Mid-Delta region due to the high quality of soil. The Northern Delta region is characterized by high salinity, especially near the Mediterranean coast and lakes. Upper Egypt is characterized by arid weather; thus, certain types of crops are being grown there. Reclaimed agricultural lands in the desert are characterized by having advanced technology; yet their constraints arise from the low fertility.

Crop cultivation in Egypt takes place during three consecutive cropping seasons; the winter, summer and Nili(late summer) seasons, depending on the irrigation rotation. Winter season crops (including wheat, barely, beans and clover) are irrigated during the period October – December, and are harvested in May.

Following the winter, crops of the summer season are irrigated from April–June and are harvested in October. Those include rice, cotton, maize and sugarcane. The cultivtion of Nili season crops takes place during the months of July and harvest takes place in November. Crops of the Nili season are mainly similar to summer crops (mainly maize, sunflower and soybean). Vegetables and fruits are grown all year round, depending on their type. Table (6.1) shows The Cropping Pattern Suggested by the Sustainable Egyptian Agricultural Development Strategy.

Table (6.1): The Cropping Pattern Suggested by the Sustainable Agricultural Strategies (Cropped area in 1000 fed.)

Community group	**2010**	**Estimates for 2017**	**Estimates for 2030**
1. Cereals			
Wheat	3066	3750	4200
Rice	1095	1250	1800
Maize	1968	3150	3700
Total Cereal Crop	7120	9038	10258
II. Sugar Crop			
Sugar Cane	320	340	350
Sugar Beet	386	500	800
Total Sugar Crop	706	840	1150
III. Oilseed Crops			
Groundnet	159	230	350
Sesame	88	85	100
Total Oilseed crop	318	378	525
IV. Legume Crops			
Broad Beans	202	300	400
Other Legumes	30	38	45
Total legumes	232	338	445
V. Fiber Crops			
Cotton	369	750	1000
Other Fibers	8	18	21
Total Fiber Crops	377	768	1021
VI. Fodder Crops			
Perennial Clover	1612	1900	2200
One-cut Clover	310	540	650
Total Fodder Crops	2685	3300	4250
Total Vegetable Crops	2112	2280	2645
Total Fruits	1377	1500	1755
Total Cropped Area	15334	19162	22984

Source: MALR, 2009 ***one feddan = 4200 m²= 0.42ha.***

6.3 Current crop patter

The recorded crop pattern in 2014/15 growing season is presented in Table (6.2). The table included the most important crops from economic point of view and less economic crops were gathered in one category, namely other winter/summer crops. The Table showed that the highest cultivated area in the winter was assigned to wheat, followed by clover. Similarly, the highest cultivated area in the summer was assigned to maize followed by rice. The total cultivated area was 6.2 million hectares in old and new lands on national level. Crop intensification ratio under this case is 172%.

Table (6.2): Cropping pattern and its applied irrigation water in Egypt during 2014/15 growing season.

Crops	Cultivated area (ha)	Applied irrigation water (m^3)
Winter crops		
Wheat	1,448,195	9,507,297,254
Faba bean	36,492	198,435,293
Clover	635,816	6,211,883,976
Onion	78,915	870,602,757
Tomato	77,973	383,613,876
Potato	113,156	390,158,856
Sugar beet	231,225	2,063,171,359
Other winter crops	251,198	2,197,786,500
Summer crops		
Cotton	100,361	1,454,893,021
Rice	506,596	7,247,805,796
Maize	942,806	9,240,715,534
Soybean	14,123	134,024,119
Sunflower	6,533	49,433,874
Potato	53,725	410,870,553
Tomato	100,876	950,465,429
Sugarcane	136,715	4,518,334,134
Other summer crops	1,514,244	16,502,149,216
Total	6,248,950	62,331,641,547

1ha=10000m²

6.4 Prevailing and suggested crops sequences

Prevailing crop sequence per year in the Nile Delta and valley involves cultivation of wheat followed by maize or rice, which are exhausting the soil (Encid,2015). A suggested crop sequence is elaborated; cereal crops should be followed egumecrops with different shallow roots crops pattern to maintain soil fertility (Table 6.3).

Table (6.3) prevailing and suggested crops sequences

Prevailing crop sequence	Suggested crops sequence
Wheat then maize	Clover (short season) wheat then maize
Wheat then rice	Clover (short season) wheat then rice
Sugar beet then maize	Sugar beet, soybean then maize
Sugar beet then rice	Clover (short season)Sugar beet then rice
Flax then maize	Flax soybean then maize (late)
Faba been then maize	Faba bean, bean then maize (late)
Garlic then maize	Clover (full season) pepper then maize (forage)
Clover (full season) then maize	Clover (full season), eggplant then maize (forage)

6.5 Water requirement with the suggested crops sequences

As proposed by (Ouda and Zohry 2017), where crop sequence as suggested in the following (table 6.4), water saving will occur. The saving will be between +25and +1517 m^3/ha (positive sign (+) under Deviations column). Such a saved is presented by large irrigation amount, namely 1517 m^3/ha which can be obtained if precise land leveling and cultivation on raised beds implemented (management package), which saves 25% of the applied water to surface irrigation. The negative sign (-)under "Deviation column" refers to shortage in the applied water, for example, for short season clover (-75 m^3/ha), for soybean (-300 m^3/ha, or -725 m^3/ha) and for bean (-354 m^3/ha). Thus, to solve this problem, deficit irrigation can be applied to the middle crop to get the benefit of improve soil fertility.

Table (6.4) Prevailing and suggested crops sequences, its water requirement and increase / or decrease in total water requirements.

Prevailing crops sequence	WR (m^3/ha)	Suggested crops sequence	WR (m^3/ha)	Deviation (m^3/ha)
Wheat then maize	16075	Clover (short season) wheat then maize	16050	+25
Wheat then rice	18800	Clover (short season) wheat then rice	18137	+662
Sugar beet then maize	18566	Sugar beet, soybean then maize	18013	+553
Sugar beet then rice	21316	Clover (short season), sugar beet then rice	21391	-75
Flax then maize	16100	Flax, soybean then maize (late)	16400	-300
Faba been then maize	15933	Faba bean, bean then maize (late)	16287	-354
Garlic then maize	16400	Garlic, soybean then maize (late)	17125	-725
Clover (full season) then maize	21066	Clover (full season), pepper then maize (forage)	20513	+554
		Clover (full season), eggplant then maize (forage)	19550	+1517

WR= water requirements

Thus, changing crop sequence from two to three crops per year can be achieved by the saving in the applied irrigation water through using management package (precise land leveling and cultivation on raised beds). Furthermore, using this system can face water scarcity, increase crops production and consequently increase food availability.

6.6 Scenarios for cropping pattern to face Water Scarcity

Four alternatives can be used to separately or together to structure a cropping pattern that can use irrigation water more efficiently, produce more crops and save water as followed:

- Suggested cropping pattern by the “Egypt sustainable agricultural development strategy strategies”
- Cropping pattern with high water productivity in the agro-climatic zones in Egypt
- Cultivation of crops on raised beds in the old lands.
- Cultivation of crops on raised beds and intercropping systems.

6.6.1Suggested cropping pattern by “the Egyptian sustainable agricultural development strategy 2030” (El-Marsafaway and other’s 2013)

Two development strategies for the agricultural sector are currently being considered:

- The Agricultural Sustainable Development Strategy towards 2017 aims at achieving a growth rate in the agricultural sector of 4.1% per annum. The strategy aims at improving the efficiency of water use in agriculture through modifying the crop pattern.
- The 2030 Sustainable Agricultural Development Strategy aims at achieving economic and social development in the agricultural sector, through achieving a number of goals, including an efficient utilization of natural agricultural resources, food security through reaching self-sufficiency of strategic agricultural crops.

Table (6.5), summarizes mainly the key targets for 2017 and 2030 regarding a better utilization of agricultural resources comparing with the present situation. The total water quantities expected to be saved as a result of improvement of field irrigation systems and reducing areas planted by rice, are 5.3 and 12.4 billion m^3 of water by 2017 and 2030 respectively. An increase in total cultivated areas to reach 9.665 million feddans(1.0 feddan=0.42hectare) by 2017 and 11.5 million feddans by 2030. The strategy also aims at maximizing the benefits from rain-fed agriculture in North Coast to cultivate key crops

Table (6.5) Estimated Land Areas and Water Quantities in 2017 and 2030

Item	Present	2017	2030
Projected Land Area (million feddans)	8.4	9.6	11.5
Areas Projected to be Reclaimed(million feddans)	-	2.250	5.0
Cropped Area (million feddans)	15.4	19.2	22.9
Intensification (%)	184	199	200
Quantity of water used in irrigation (billion m^3)	58	61	64
field water use efficiency (%)	50	75	80
total water quantities expected to be saved as a result of developing the irrigation system (mn m^3)	-	5,300	12,400
average water share per feddan	6,900	6,320	5,565
average return per water unit (egp)	1.91	3.2	4.17

Source: MALR,2009

- **Proposed scenario for the best possible cropping Pattern**

A study is conducted to propose the cropping pattern according to the available water resources under two water use efficiency conditions of 60% and 65% (table 6.6). Two main assumptions are identified in determining the best possible cropping pattern: i.e. land allocation and water requirements to minimize the use of water.

In this scenario, fixing the cultivated area of rice at 1100 thousand feddans and increasing the cultivated areas of sugar beet and cotton by 50%. On the other hand fixing all cultivated areas of the other crops as stated in the sustainable agricultural development strategy towards 2017,table (6.5).

According to this cropping pattern scenario, the common is to fix the cultivated areas of all crops, except rice, sugar beet and cotton. It is understandable that the rice crop is playing a very serious role in the amounts of the agricultural water requirements, as it is considered a very high water consumer. With respect to sugar beet, it will compensate for the shortage in sugarcane yield, as its cropped area will be decreased through the different scenarios, due to its high water consumption. Cotton is measured strategically as one of the most important national crops in Egypt and any increase in this crop yield will lead to an increase in the national income.
With this objective, greater attention should be paid to the development and cultivation of high salinity resistant varieties suitable for the use of agricultural

drainage water, in addition to early maturing varieties that lead to saving in irrigation water and achieving higher crop intensification rates.

Table (6-6) Cropping pattern under two water use efficiencies

Crop	Cropped Area (1,000 feddan)	Water Requirements (billion m^3) under Water use efficiency	
		60%	65%
Wheat	3750	10.96	9.50
Rice	1100	7.62	6.60
Maize	2000	7.55	6.93
Other Grains	700	2.15	1.87
Broad Beans	250	1.15	1.00
Sugar Beet	600	1.62	1.40
Clover	2500	5.77	5.00
Sugar Cane	320	3.36	3.10
Cotton	560	2.51	2.18
Vegetable	2000	4.55	3.86
Fruits	1377	7.77	6.55
Total	**15177**	**46.42**	**41.77**

6.6.2. Crop water productivity with the cropping Pattern under Agro Climatic Zones

The Second study was made by (El-Marsafawy, Samia et al., 2013), with the objective of optimizing cropping pattern to achieve more crops per drop concept under different climatic zones (Nile Delta, Middle Delta and Upper Egypt).

Crop water productivity (CWP) or water use efficiency (WUE) as kg/per m^3 an efficiency term expressing the amount of output in relation to the amount of input (cubic melers of water) needed to produce that output. The water use efficiency (WUE) for crop production is referred to the combination of water lost (due to evaporation from the soil surface and that transpired from the plants canopy) and the resultant marketable. Crop rotation plays an important role in effecting water productivity, soil productivity as well as increasing crop production. Many crops are affected and often sensitive to the crop rotation and the preceding crops.

Crops Pattern Scenarios

Studies on crop water productivity under different agro -climatic zones in Egypt were done to determine the optimum crop pattern that could achieve the highest yield from irrigation water use unit or more crops per drop. To attain such goal different scenarios of cropping pattern were suggested as follows:-

- wheat + maize
- wheat + rice
- wheat + soybean
- wheat + sunflower
- wheat + tomato (s)
- wheat + potato (s)
- wheat + pepper (s)
- barley+ maize
- barley + rice
- barley + soybean
- barley + sunflower
- barley + tomato (s)
- barley + potato (s)
- barley + pepper (s)
- sugarcane
- Tomato (w) + maize
- Tomato (w) + rice

* Tomato (w) + soybean
* Tomato (w) + sunflower
* Tomato (w) + potato (s)
* Tomato (w) + Pepper (s)
* Potato (w) + maize
* Potato (w) + rice
* Potato (w) + soybean
* Potato (w) + sunflower
* Potato (w) + tomato (s)
* Potato (w) + Pepper (s)
* Pepper (w) + maize
* Pepper (w) + rice
* Pepper (w) + soybean
* Pepper (w) + sunflower
* Pepper (w) + potato (s)
* Pepper (w) + tomato (s)

It should be notified that w and s letters are referred to winter and summer seasons, respectively.

For estimating crop water productivity or water use efficiency, the potential evapotranspiration "ETp" according to the available meteorological data for Delta, middle Egypt and Upper Egypt were used. Penman Monteith was using crop WAT model, Smith, (1991).

To account the effect of the crop characteristics on crop requirements, crop coefficient "Kc" is used. Thus, ET crop can be estimated for some major field crops as presented in Table (6.7) according to the following relation:

$$ET\ crop = Kc \times ETp$$

Table (6.7): Yield* (Kg/fed), ET crop (consumptive use m^3/fed) and crop water productivity, Kg /m^{-3} of water consumption "CWP")for some major crops in Egypt.

crop	Nile Delta			Middle Egypt			Upper Egypt		
	Yield	**Et crop**	**CWP**	**Yield**	**Et crop**	**CWP**	**Yield**	**Et crop**	**CWP**
wheat	2749	1247	2.20	28321	1425	1.99	2821	1544	1.83
barley	1737	925	1.88	1358	1099	1.25	1244	1153	1.08
maize	3557	2118	1.68	3433	2420	1.36	3334	2714	1.23
rice	4043	3065	1.32	1548	3498	0.98			
soybean	1223	2307	0.53	936	2640	0.59	1338	2875	0.47
sunflower	958	1740	0.55	926	2013	0.46	1165	2173	0.54
sugarcane	37006	5724	6.47	44046	6694	6.58	50039	7452	6.71
Tomato(s)	13974	2519	5.55	18156	2955	6.14	16841	3208	5.24
Tomato(w)	18175	1502	12.10	18158	1782	10.19	24802	2040	12.16
Potato (w)	10812	1035	10.45	10465	1232	8.71	17698	1432	12.36
Potato (s)	12260	1555	7.88	7005	1861	5.62	14634	2061	7.10
Pepper (w)	6877	1189	5.78	8392	1413	5.94	5780	1646	3.51
Pepper (s)	7215	2572	2.81	---	2969	2.83	9146	3224	2.84

*Source: Agricultural Economic Bulletin, 2009

For the determination of water requirements of a specified crop, irrigation efficiency have been taken into consideration. The efficiency of irrigation water is the ratio between the theoretical water consumptive use and actual irrigation requirements. According to **Jensen (1980),** irrigation efficiency values for surface, sprinkler and drip irrigation systems are 60, 75 and 90 %, respectively. Meanwhile, for sub-merged crop, i.e., rice an irrigation efficiency of 50% is used (Dastane, 1972).

Crop Water Productivity (CWP):

According to Smith (2002) Crop water productivity is defined as Crop yield per Water consumptively used (ET).

Results in Table (6.8), indicate the different scenarios of cropping pattern in Nile Delta, Middle and Upper Egypt (to represent different agro climatic zones in Egypt) and the optimum ones.

Table (6.8): Crop water productivity (CWP) under different scenarios of cropping pattern in Nile Delta, Middle and Upper Egypt

Cropping pattern	CWP, Kg m^{-3} year^{-1}		
	Nile Delta	Middle Egypt	Upper Egypt
wheat + maize	1.94	1.68	1.53
wheat +rice	1.76	1.49	-
wheat + soybean	1.37	1.29	1.15
wheat + sunflower	1.38	1.23	1.19
wheat + tomato (s)	3.84	4.39	3.54
wheat + potato (s)	5.04	3.81	4.47
wheat +pepper (s)	2.51	2.41	2.34
barley+ maize	1.78	1.30	1.16
barley +rice	1.60	1.11	-
barley + soybean	1.21	0.92	0.78
barley + sunflower	1.22	0.85	0.81
barley + tomato (s)	3.68	4.01	3.17
barley + potato (s)	4.88	3.43	4.09
barley + pepper (s)	2.35	2.04	1.96
Sugarcane	6.47	6.58	6.71
Tomato (w) + maize	6.89	5.78	6.70
Tomato (w) + rice	6.71	5.59	-
Tomato (w) + soybean	6.32	5.39	6.32
Tomato (w) + sunflower	6.33	5.33	6.35
Tomato (w) + potato (s)	9.99	7.91	9.63
Tomato (w) + Pepper (s)	7.46	6.51	7.50
Potato (w) + maize	6.07	5.04	6.80
Potato (w) + rice	5.89	4.85	-
Potato (w) + soybean	5.49	4.65	6.42
Potato (w) + sunflower	5.50	4.59	6.45
Potato (w) + tomato (s)	7.97	7.75	8.81
Potato (w) + Pepper (s)	6.63	5.77	7.60
Pepper (w) + maize	3.73	3.16	2.37
Pepper (w) + rice	3.55	2.97	-
Pepper (w) + soybean	3.16	2.78	1.99
Pepper (w) + sunflower	3.17	2.71	2.03
Pepper (w) + potato (s)	6.83	5.29	5.31
Pepper (w) + tomato (s)	5.63	5.87	4.38

Note: Due to the absence of rice cultivation in Upper Egypt, the scenarios of cropping patterns dropped other scenarios which including rice crop. There is no rice in Middle Egypt

In Nile Delta region, the highest CWP (9.99 kg/ m^3 water consumption per year) was obtained for the scenario of tomato (w) + potato (s), meanwhile, the lowest scenario was registered for barley + soybean (1.21 kg/m^3 water consumption kg/m^3 per year).

Finally, the results indicated that higher crop water productivity, under different scenarios of cropping pattern at three main ago-climatic zones, were recorded with the cropping pattern which include vegetable crops. Irrigation, water is applied to the bottom of the furrows which reduce the irrigation time and the amount of irrigation water. The wetted area is less than in the traditional methods hence irrigation cost is reduced

6.6.3. Cultivation on raised beds in the old lands

A feature of the raised beds planting system is the hole between the beds. This hole comprises the unplanted shoulder of a bed, the furrow itself and the shoulder of the adjacent bed. It increases the ability of the cultivar to capture solar radiation falling in these holes between the beds (Fischer et al., 2005). Changing cultivation methods from cultivation in basins or on narrow rows (0.6 m in width) to raised beds (1.2 m in width) represents an opportunity here to save on the applied irrigation water to crops. Furthermore, raised beds cultivation has shown to reduce seed mortality rates; increases water and nitrogen use efficiency, and improves soil quality. In addition, less labor is required for irrigation and fertilizer and it is better managed relative to conventional flat planting (Limon-Ortega et al., 2002). Moreover, it can reduce crop lodging (Wang et al., 2009) and it exert control on applied water resulting in less water and nutrient loss through deep percolation, and reduced total water requirements (Dogan and Kirnak., 2010). Thus, raised beds planting saved a reasonable amount of applied irrigation water could reach to an average of 40%, as compared to flat planting (Kumar et al. 2010). In Egypt, this method proved to save 20% of the applied water to crops under surface irrigation (Abouelenein et al., 2011). Majeed et al., (2015) indicated that raised beds planting of wheat not only saves water but improved fertilizer use efficiency and increase grain yield by 15% compared to flat planting. Raised beds cultivation significantly and substantially increased maize growth, microbial functional groups and enzyme activities compare to flat planting, thus it increasing availability of essential crop nutrients by stimulating microbial activity (Zhang et al., 2012).

Fig,(6.1) Wheat cultivated on raised beds

Table (6.9) showed that a large amount of applied water to surface irrigation in the old land can be saved if crops cultivated on raised beds, namely about 9.5 billion cubic meters. This amount of saved irrigation water can be used to irrigate an area about 1.3 million hectares in the sandy lands under sprinkler or drip irrigation systems. We assumed that the saved irrigation water from "other winter crops" will be used to increase the cultivated area of wheat. Similarly, the saved irrigation water from "other summer crops" will be used to increase the cultivated area of maize to reduced production-consumption gaps for these two crops. Thus, the potential total cultivated area will be about 7.5 million hectares.These cultivated area irrigated with the same amount of irrigation water presented in Table (6.1). Crop intensification ratio under this case is 176%.

Table (6.9): Potential saved irrigation water, new cultivated area and total cultivated area under raised beds cultivation.

Crops	Savedirrigation water (m^3)	New cultivated area (ha)	Totalcultivated area (ha)
Winter crops			
Wheat	1,569,981,472	330,053	1.778.248
Faba bean	24,701,648	5,560	42.053
Clover	1,146,188,403	143,863	779.679
Onion	123,503,720	13,045	91.960
Tomato	34,750,449	8,149	86.122
Potato	61,054,620	20,993	134.148
Sugar beet	330,645,557	44,128	275.354
Other winter crops	238,981,680	0	251.198
Summer crops			
Cotton	267,153,178	25,246	125.607
Rice	1,344,760,879	93,994	600.590
Maize	1,723,535,377	534,843	1.477.648
Soybean	26,202,511	3,875	17.999
Sunflower	5,548,153	878	4.410
Potato	70,745,980	12,387	66.112
Tomato	88,441,454	10,875	111.751
Sugarcane	407,348,537	14,148	150.863
Other summer crops	2,080,756,840	0	1.514.244
Total	9,544,300,459	1,262,036	7,510,985

Source: Ouda, 2017

6.6.4. Raised beds cultivation and intercropping of crops

Intercropping crops on other crops is a useful technique to increase productivity per unit area, where one crop share its life cycle or part of it with another crop (Eskandari et al., 2010). This practice can be used as a way to improve soil fertility, increase land productivity and save on the applied irrigation water (Kamel et al., 2010), as well as increase water productivity as a result of using less water to irrigate two crops (Andersen, 2005). The conventional ways of intensifying crop production are vertical and horizontal expansions. Intercropping offers two additional dimensions, time and space. The intensification of land and resources use in space dimension is an important aspect of intercropping. It enhanced the efficient use of light as two or more species that occupy the same land during a significant part of the growing season and have different pattern of foliage display (Francis, 1986). Furthermore, different rooting patterns can explore a greater total soil volume because of the roots being at different depths (Francis, 1986). These differences in foliage display and rooting patterns create the space dimension of intercropping (Dunn et al. 1999). Implementing intercropping on raised beds can save on the applied irrigation water to surface irrigation (Zohry and Ouda 2017).

Three strategic crops can be intercropped with other crops, namely wheat, maize and faba bean. Many successful intercropping systems with wheat were proved to increase wheat land and water productivities in Egypt, such as wheat intercropping with tomato (Abd El-Zaher et al.,2013). In this system, we assumed that 45% of the cultivated area with winter tomato will be assigned to be intercropped with wheat and wheat will produce 80% of its yield under sole planting (Figure 6.2a).Relay intercropping cotton with wheat can also be implemented(Zohry 2005), where wheat is cultivated on raised beds in November and in March cotton is cultivated on the two edges of raised beds. Thus, both wheat and cotton shares two irrigation before wheat harvest inMay and cotton continue its growth season until September (Fig, 6.3).

a)Wheat intercropped with tomato	b) Relay intercropping cotton on wheat
	

Fig, (6.2) wheat intercropping systems

Furthermore, wheat intercropped with sugarcane (Ahmed et al., 2013)and wheat intercropped under young fruit trees proved to increase wheat cultivated area without any reduction in the productivity of the main crop(Kamel2011).Regarding to intercropping wheat on sugarcane and under fruit trees, we assumed that 17% of its cultivated area will be used for intercropping. Furthermore, wheat productivity will be 50 and 70% under intercropping on sugarcane and under fruit trees, respectively.

Regarding to intercropping systems with maize, maize intercropped with tomato(Mohamed et al., 2013, Fig, 6.3a), soybean or cowpea intercropped with maize (Sherif and Gendy2012, Fig, 6.3) and maize intercropping with peanut(Abd El-Zaher et al., 2007).

a) Maize intercropped with tomato | b) Maize intercropped with soybean

Fig, (6.3) maize intercropping systems

We assumed that 90% of the cultivated area with summer tomato will be assigned to be intercropped with maize. Furthermore, maize plants will produce 70% of its yield under sole planting. Regarding to soybean intercropping with maize, we assumed it will be done on 100% of the cultivated area of soybean. Furthermore, maize intercropping on peanut will be on 30% of the cultivated area of peanut and it will produce 40% of maize yield under sole planting.

With respect to faba bean intercropping with other crops, there are three popular intercropping systems in Egypt, namely faba bean intercropped with winter tomato(Abd El-Aal and Zohry 2004, Fig, 6.4a), faba bean intercropped with sugar beet (Abd El-Zaher et al., 2014, Figure 6.4b) and and faba bean intercropped with sugarcane in Upper Egypt (Farghaly 1997).We assumed that 45% of the cultivated area with winter tomato will be assigned to be intercropped with faba bean and it will produce 60% of its yield under sole planting. Regarding to intercropping faba bean with sugar beet, we assumed it will be done on 30% of the cultivated area of sugarcane and faba bean will produce 25% of its yield under sole planting.

a) Faba bean intercropped with tomato

b) Faba bean intercropped with sugar beet

Fig, (6.4) faba bean intercropping systems

Table (6.10) indicated that new cultivated area with wheat, maize and faba bean can be added as a result of intercropping, namely 197,669, 71,785 and 112,585hectares.Table (6.10) also showed that a total area of 382,068 hectares can be added to the national cropped area as a result of intercropping. These areas do not need irrigation water to grow these three crops as it obtained its water requirements from the applied water to the intercropped crops

Table (6.10) new cultivated areas with wheat, maize and faba bean as a result of intercropping.

Crop	Actual area (ha)	Intercropped with	Suggested area (ha)
Wheat	1,448,195	Cotton Tomato (winter) Sugarcane Fruit trees	80,193 12,943 20,211 84,353
Total			197,699
Maize	942,806	Tomato (summer) Soybean Peanut	17,272 6,839 47,674
Total			71,785
faba bean	36,492	Sugar beet Tomato (winter) Sugarcane	79,431 12,943 20,211
Total			112,585
Grand total			382,068

Adding the cropped areas presented in Table (6.10) to the area presented in Table (6.9) resulted in an increase in the total cropped area. It is worth noting that these areas will be irrigated with the same water presented in Table (6.9). Thus, the total cultivated area will be around 7.89 million hectares. Crop intensification ratio under this case will be 186%.

Table (6.11): Expected crop pattern under raised beds cultivation and intercropping.

Crops	Cultivated area (ha)	Applied irrigation water (m^3)
Winter crops		
Wheat	1,975,947	9,507,297,254
Faba bean	154,637	198,435,293
Clover	779,679	6,211,883,976
Onion	91,960	870,602,757
Tomato	86,122	383,613,876
Potato	134,148	390,158,856
Sugar beet	275,354	2,063,171,359
Other winter crops	251,198	2,197,786,500
Summer crops		
Cotton	125,607	1,454,893,021
Rice	600,590	7,247,805,796
Maize	1,549,433	9,240,715,534
Soybean	17,999	134,024,119
Sunflower	7,410	49,433,874
Potato	66,112	410,870,553
Tomato	111,751	950,465,429
Sugarcane	150,863	4,518,334,134
Other summer crops	1,514,244	16,502,149,216
Total	7,893,054	62,331,641,547

6.6.5 Cultivation on raised beds, intercropping and cultivation of three crops per year

Changing crop sequence from cultivation of two crops per year (winter then summer crop) to three crops per year winter, fall then summer crop) or winter, early summer then late summer crop) can help in solving food gaps problems in Egypt. Furthermore, using this practice can improve and sustain soil fertility and increase farmers' income (Sheha et al., 2014). The saved irrigation water from cultivation on raised beds can be used to irrigate the third crop. We suggested cultivation of short season clover as early winter crop in September and its harvest occur in November. Sunflower, soybean and maize can be cultivated as early/late summer crops. The suggested areas are presented in Table (6.12).Short season clover is suggested to be planted in 500 thousand hectares, which requires 3.48 billion cubic meters of irrigation water. Short season clover can solve part of summer feed gap in Egypt. Furthermore, sunflower and soybean cultivation can be done as an early summer crop in 208.3 and 125.0 thousand hectares to reduce edible oil gap in Egypt. Finally, maize can cultivated in 335.4 thousand hectares as late crop to reduce maize production-consumption gap in Egypt. The total area increase will be around 1.17 million hectares (Table 6.5). The total required irrigation water to be applied under this situation is 9.5 billion cubic meters, which almost equal the saved amount from cultivation on raised beds.

Table (6.12) Suggested cultivated area of the suggested crops and its applied irrigation water

Suggested crop	Suggested area (ha)	Applied irrigation water (m^3)
Short season clover	500,000	3,480,000,000
Sunflower	208,333	1,589,000,000
Soybean	125,000	1,186,200,000
Maize	335,417	3,287,516,785
Total	1,168,750	9,542,716,785

Table (6.13) showed examples of suggested three crops per year practice including crops in Table (6.12).

Table (6.13) prevailing and suggested crop sequences

Prevailing crops sequence	Suggested crops sequence
Wheat then maize	Clover (short season), wheat then maize
Wheat then rice	Clover (short season), wheat then rice
Sugar beet then rice	Clover (short season), sugar beet then rice
Sugar beet then rice	Sugar beet, sunflower then rice
Clover then maize	Clover, sunflower then maize (late)
Pea then maize	Pea, sunflower then maize (late)
Flax then maize	Flax, soybean then maize (late)
Faba been then maize	Faba bean, soybean then maize (late)
Sugar beet then maize	Sugar beet, soybean then maize (late)
Clover then rice	Clover, soybean then rice

Source: Ouda and Zohry (2017)

Table (6.14) presented the total cultivate area after the addition of new cultivated area with short season clover, sunflower, soybean and maize. The total cultivated area will reach 7.8 million hectares and it will consume 62.3 billion cubic meters of irrigation water, which is the available to agricultural sector in the national water budget. In this case, the crop pattern will be implemented on raised beds and includes added area from intercropping systems, which not required the addition of extra irrigation water than the currently available. It also contains the added area from cultivation of three crops per year and that will use the saved water from cultivation on raised beds. Crop intensification ratio under this case will be 217%.

Table (6.14): Expected crop pattern under raised beds cultivation, intercropping and cultivation of three crops per year.

Crops	Cultivated area (ha)	Applied irrigation water (m^3)
Winter crops		
Wheat	1,645,895	7,937,315,782
Faba bean	149,077	173,733,645
Clover	635,816	5,065,695,573
Short season clover	500,000	3,480,000,000
Onion	78,915	747,099,037
Tomato	77,973	348,863,427
Potato	113,156	329,104,236
Sugar beet	231,225	1,732,525,802
Other winter crops	251,198	1,958,804,820
Summer crops		
Cotton	100,361	1,187,739,843
Rice	506,596	5,903,044,917
Maize	1,350,007	10,804,696,942
Soybean	139,123	1,294,021,608
Sunflower	214,866	1,632,885,721
Potato	53,725	340,124,573
Tomato	100,876	862,023,975
Sugarcane	136,715	4,110,985,597
Other summer crops	1,514,244	14,421,392,376
Total	7,799,768	62,330,057,874

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Chapter 7

Innovation Water Saving Approaches and Case Studies

Chapter 7
INNOVATION WATER SAVING APPROACHES AND CASE STUDIES

7-1 Introduction

Today, agriculture sector in Egypt is facing a complex challenge of producing more food with less water. The demand for food is driven primarily by population growth which expected to increase from 92 m^3 billion in 2016 to 150 billion in year 2050. Water is already a limiting factor for agriculture production. Climate change is likely to enhance the water requirements due to temperature increase which will in turn amplify the water scarcity. Thus, there will not be enough water to produce the food needed. It is therefore imperative to develop and promote water saving practices on large-scale in agriculture to cope with water scarcity.

Water saving activities: Agriculture sector is considered to have the highest potential for water saving. The agricultural sector represents around 85% of total demand; a large amount of water is lost or misused. There is a high opportunity for saving significant volumes of water losses through a better use of technical and economical tools.

The following case studies demonstrate possible ways of water savings in the agriculture sector.

7.2 Water Saving Approaches in Irrigated Agriculture

The water saving approaches in irrigated agriculture (including drainage management) may be grouped into two broad categories as (a) conventional, and (b) non-conventional. Various measures under each of these categories are enlisted as follows: (ICID, 2008)

(a) Conventional

- Engineering
    - Lining of conveyance and distribution network,
    - Adopting better on-farm water application techniques like micro and sprinkler systems,
    - Precision/laser land leveling;
    - Artificial recharging of aquifers.

- **Agronomic**
  - Applying water at the critical growth stages of crops,
  - Irrigation scheduling based on soil-crop climatic factors,
  - Selecting crop (varieties) with higher yields per unit of water, switching from high water consuming crops to less water consuming crops.
- **Management**
  - Improved operation and maintenance of irrigation and drainage system,
  - Promoting participatory irrigation (and drainage) management (PIM).

- **Institutional**
  - Capacity building and training of irrigation managers, field staff, and farmers,

(b) Non-Conventional

- **Innovative technologies**
  - Use of low energy precision application (LEPA) irrigation systems.
  - Water tellers.
  - Use of internet, mobile communication and remote sensing.
- **Innovative management**
  - Integrated water resources management.
  - Involvement of women in irrigation management.
  - Public-private – partnership.

7.3 Water Resources Management in Egypt

Comprehensive water management programs are being implemented in Egypt to raise water use efficiency and increase crop production. Most of these programs included:

- Improvement and modernization of water distribution system at both the macro and micro levels.
- Soft measures dealing with institutional reform, which lies at the heart of the integrated approach by the MWRI for the management of its water resources.

  These programs aims to strengthen, the political, technical, legal, and administrative arrangements that lead to saving water and in general maximizing returns from investments available to water sector in Egypt.

- **Measures for better use of water resources**

Measures aiming at a better use of existing resources focus on improving the efficiency of the water resources system. The water use efficiency in agriculture can be improved by many measures, in particular by:

- Continuing improvement project activities (A package of land leveling, lining canals, and forming water user associations. This saves 10-15% of irrigation water use.
- Improvement of the physical infrastructures.
- Rehabilitation of the irrigation system.
- Rehabilitate existing grand barrages and control structures on the Nile and main canals.
- Reviewing the present drainage water re-use policy e.g by applying intermediate reuse.
- Introduction of new crop varieties such as early maturing and short duration rice varieties and salt tolerant seeds and shifting of cropping crops while still achieving the food-self-sufficiency and food security policies of the country.
- With respect to the municipal and industrial sectors, water use efficiency can be improved to reduce losses in the networks. i.e. Demand management through installation/rehabilitation of the maturing system and promotion of the application of water saving technologies in industry and reduction of leakage losses, through repair based on priorities for urgent rehabilitation work.

- **Cost recovery in irrigation and drainage**

The advantages of the cost recovery of irrigation projects are :

- Reducing the burden over the government, paying the infrastructure cost of irrigation projects and then recovering the cost over a long period.
- Encouraging farmers to save irrigation water in order to reduce their water transfer tariff, later.
- Egypt has managed successfully in implementing a cost – recovery mechanism on introducing the subsurface drainage system for more than 90% of the irrigated areas. Cost recovery is simply as the total of the contractor's billings.
- A cost recovery over 20 years is being applied to recover the costs of improvement, and development of mesqa which deliver irrigation water to farm lands through water user association.

7.4 Case Studies of Water Saving in Egypt

Egyptian agriculture possesses certain features that make it unique among other agricultural systems all over the world. The old lands in the Nile Valley are the main growing areas in Egypt that are characterized by complex-year long cropping patterns. The Northern Delta region is characterized by high salinity; especially near the Mediterranean coast and lakes. Upper Egypt is characterized by arid weather, thus certain types of crops are being grown.

Crop cultivation takes place, during three consecutive cropping seasons; the winter summer and nili (kharif) season depending on the irrigation rotation. Winter season crops (including wheat, barley, beans and clover) are irrigated during the period (October – March), and are harvested in April- May. Following the winter crops of the summer seasons are irrigated from April – July and are harvested in October. These include rice, cotton, maize and sugar cane. The irrigation of nili season crops takes place during the months of July and August and harvest takes place in November (maize, peanuts, and cotton) .Vegetables and fruits are grown all year round depending on their type. Great efforts are paid to increase the productivity of the cultivated area by using high yielding cultivars and improving the agronomic practices such as planting methods, irrigation management under such lands either by surface irrigation or other new methods (drip, sprinker) and introducing innovative technologies are all important to improve production and water saving. The following are some case studies of water saving in Egypt.

Case study 1: Water Saving: Maize Crop

By: Dr. A Swelam and Dr. Yosri Atta** and later extended by Dr. Yosri Atta.*

1. Introduction

Maize is of one of the most important cereal crop in Egypt and it is sown as a summer crop for human consumption, animal feeding and industrial purpose especially for oil and starch production. The local production of maize did not cover the local consumption.

Therefore, great efforts are paid to increase the productivity of the cultivated area by using high yielding cultivars and improving the agronomic practices such as planting method. Significant differences among maize hybrids in growth, yield and its components were obtained, Atta-Allah, 1996 and Khedr et al, 1995.

Irrigation management under old lands conditions which irrigated by surface irrigation method is very important to improve production and water saving. Surface irrigation as method of traditional irrigation which has lower application efficiency because the water losses, like any system, are mainly due to deep percolation, particularly in the upper part of the field and comprising not less than 45% causing several acute problems i.e. raising ground water table, leaching of nutrient …etc consequently, such problems are negatively affecting crop yield and reducing fertilizer and water use efficiencies.

The irrigation of maize through its growing season using the optimum amount of water is considered a very important process for increasing productivity. Farmers got used to over irrigate their fields, where losses of water are great. On the other hand, water use efficiency will be improved without additional costs to the farmers. Hence, the best timing of irrigation and controlling amounts of water could achieve a good water management, where the strategy of irrigation policy in Egypt aims to optimizing the irrigation water. Therefore it is necessary to find out a new planting method and new surface irrigation technique should be applied to increasing the irrigation application efficiency, water saving, field water use efficiency as well as yield and quality according to the method described by Atta and Ibrahim, 2005.

The aim of this study was to investigate the effect of planting method on growth, yield, its attributes and some water relation as well as net return for two maize cultivars.

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2. Description of the New Methodology of Water Saving

This method depends on reducing irrigated area of furrows by adapting different spacing (80 or 160 cm) apart as shown in figures (7.1) (7.2), (7.3). Top and bottom of the furrows are known as border and tape respectively. Every one border and tape was named (Strip of furrow). Grains were planted in tapes as the same plant density (as recommended) in one or two rows of plants according to strip width. First irrigation was given with enough amounts of water to produce saturation effect at borders to fix the dimension of the strip. Next irrigations were given for tapes only in addition to a small part on both sides of furrows as a result of water flow in these tapes. Accordingly, wetted area of the strip was decreased by about 30 to 50% and consequently water saving occurred by about this ratio without decreasing the yield. Using this new method increased irrigation application efficiency, fertilizers use efficiency, water productivity, and decreased percolation losses and evaporation.

Field work

The field experimental work was conducted during 2005 and 2006 seasons and then extended to years, 2010, and 2011 for a cultivated areas of 50 hectares distributed on different sites at Zankalon experimental field; (Water Requirements Research Station El-Sharikia Government, of Water Management and Irrigation Systems Research Institute, National Water Research Center), which is located in Eastern part of Nile Delta region in Egypt. The site is located at 30^{o} – 35' N. latitude and 31^{o}- 30' E. longitude with an elevation of about 7 meters above sea level. Soil samples were collected to determine some soil physical and chemical properties of the experimental site. The average values of soil physical and chemical properties (at different soil depths down to 60 cm) are shown in Table (7.1).

Table (7.1) Soil physical and chemical properties of the experimental site

	Particle size (%)			Texture	Bulk density (gm/cm^3)	Field capacity (%)	Wiltin g point (%)	Availab le water (%)	E.C dS/m	pH (1:2.5)
	Sand	Silt	Clay							
0-15	25.80	28.90	43.51		1.25	43.51	23.55	19.96	1.40	8.1
15-30	25.12	30.10	42.50		1.s27	40.50	21.06	19.44	1.22	8.0
30-45	26.90	31.50	40.50		1.32	37.12	17.59	19.53	1.25	8.1
45-60	29.78	31.50	37.12		1.40	36.25	16.62	19.63	1.05	8.02
Average	26.90	30.50	40.91	Clay	1.32	39.34	11.65	19.64	1.23	8.03

The experiments were performed to study the effect of planting methods on growth, yield, its attributes and some water relations as well as net return for two maize cultivars.

Grains were planted with population density of 5714 plants/ha on June 5 and 7 in both seasons respectively.

Fertilization

Calcium super phosphate (15.5% P_2O_5) was added at a rate of 240 kg/ha during land preparation. Nitrogen fertilizer was added as urea (46% N) at a rate 285 kg/ha in two equal doses i.e. before the first and the second irrigations. After complete germination, the plants were thinned to attain the recommended plant density. All other cultural practices of growing maize plants were applied as practiced in the area. Harvest dates were done on October 9th and 13th in both seasons, respectively.

- **Main plots (Planting methods)**

Planting methods were arranged in three treatments as follows:

1. Traditional Planting Method

Treatment A: Traditional method (planting on furrow 80 cm width):

Furrows width was 80 cm, with one row of plants, 22 cm in between. Grains were planted on top of furrow to attain 57140 plant/ha, as shown in figure (7.1)

2. The New Planting Method

The new method of planting namely strips of furrows is dependent on decreasing the irrigated area where the furrows were shaped then widened. Each furrow consisted of top of furrow which named border and bottom of furrow which named tape. Every one border and one tape were named strip of furrow. Grains were planted in bottom of furrow tape by using the same plant density of traditional method with one or two rows of plants. The new method of planting included two treatments (B and C) as follows: (Photo .1,2)

Treatment B: planting on strip of furrows 80 cm width (bottom of furrows):-

Furrows width was 80 cm, with one row of plants, 22 cm in between. Grains were planted in bottoms of furrows (tapes) using the same plant density of traditional method as shown in Figure (7.2)

Treatment C: planting on strip of furrows 160 cm width (bottom of furrows):-

Furrows width was 160 cm, with two rows of plants, 22 cm in between. Grains were planted in bottoms of furrows (tapes) using the same plant density of traditional method as shown in Figure (7.3).

Generally, irrigation water was added to the tapes only, in addition, to small part of both sides of furrow as a result of water flow in these tapes (bottom of furrows). Irrigation intervals was kept the same as the traditional farmers commonly irrigated their fields.

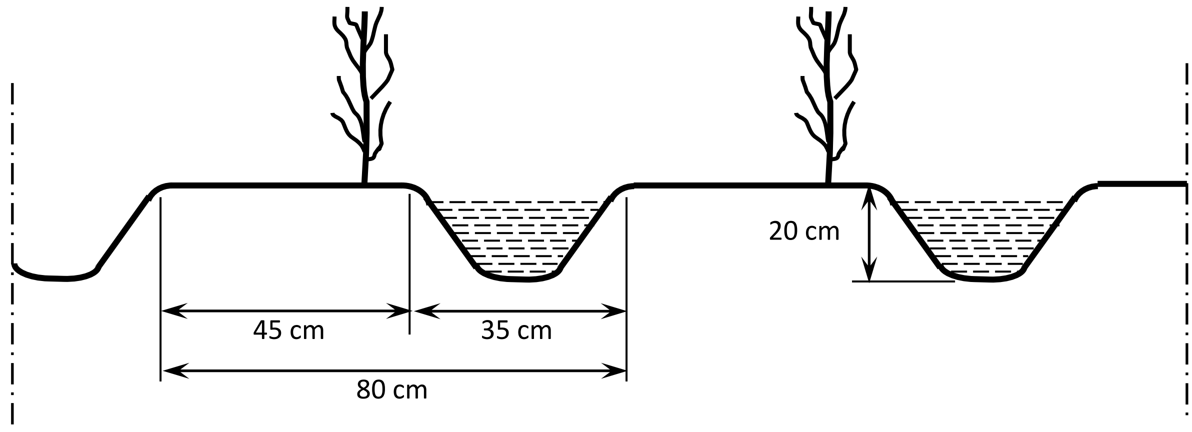

Fig.(7.1) Cross section indicating traditional planting method (Furrow 80cm width with one row of plants on top of furrow 22 cm in between to gave 57140 plants/ha).

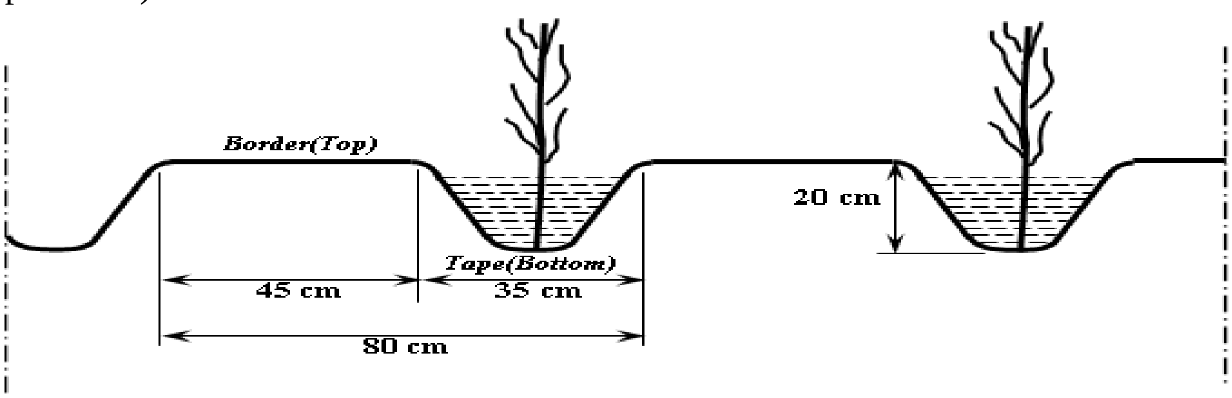

Fig.(7.2) Cross section indicating strips of furrow 80cm width with row of plants in bottom of furrow (tape) 22cm in between to give 57140 plant/ha.

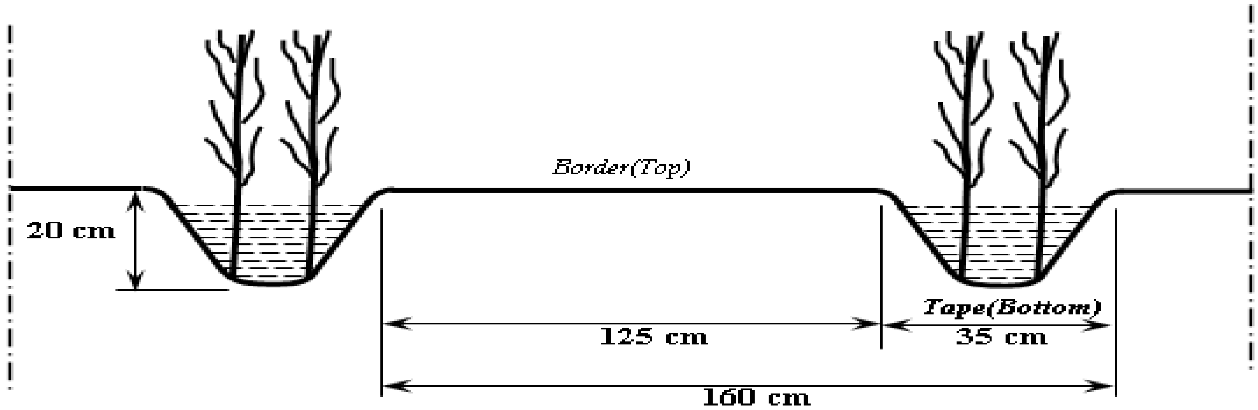

Fig.(7.3) Cross section indicating strips of furrows 160 cm width with two rows of plants in bottom of furrow (tape) 22 cm in between to give 57140 plant/ha.

Photo :1 Furrow 80 cm spacing (Traditional and modified methods)

Photo 2: Strip 160 cm spacing (bottom of furrow)

- Sub-plots (Maize cultivars)
  - Three way cross (T.W.C. 321)
  - Three way cross (T.W.C. 322)

The total number of experimental plots were 24. Area of each plot was 320 m^2 (20 m length X 16 m width) with a border of 1.5 m between them to avoid lateral percolation.

Data collected for each season was statistical analysed and the combined analysis of the two seasons were applied according to the method adopted by Steel and Torrie (1980). The treatments means were compared using the least significant differences (L.S.D) method.

3. Water relations

a. Irrigation water applied (IWA)

The amounts of irrigation water applied for each treatments during growing seasons were measured by calibrated flow meter (m^3) for each irrigation. Irrigation water was transmitted to each plot through polyethylene pipes of 6 inches in diameter and there was a valve in front of each plot. Accordingly controlling in distribution of irrigation water for each plot could be achieved. The maize plant received 7 irrigations through growing seasons including planting irrigation which was given by equally amounts for all treatments until soil saturation for all area. It was heavy, but do not leave water stay over soil surface for more than 10 hours. First irrigation was started after 21 days from planting then irrigation interval was each 14 days. After 90 and 95 days from planting in both seasons, the irrigation was stopped.

b. Water productivity (WP): WP = Grain yield (kg/ha)/ water applied (m^3/ha).

4. Crop data

a. Growth: At tasseling, ten plants were chosen randomly from each plot to determine: Plant height (cm) and Ear height (cm).

b. Yield components: At harvest time, the number of all competitive plants in the third and fourth rows was counted and harvested separately from each plot, then number of ears/plant was recorded. In the meantime, ten ears randomly chosen from each plot were kept in sunny dry place till fully dried and used to estimate the following traits:

- Number of ears/plant
- Ear length (cm).
- Ear diameter (cm).
- Weight of ears (gm).
- 100-kernel weight (gm): adjusted to 15.5% moisture content.

Grain yield: In order to determine grain yield/fed, a central area 70 m^2 of each plot were harvested and ears were collected then shelled grains and weighed as well as adjusted to 15.5% moisture content.

5. Economic Analysis

Cost of irrigation in the whole season for different methods was calculated on the basis of cost of water pump (7.7 HP), discharge 75 m^3/hr at a rate of 1 US $/hr.

$$\text{-Cost of irrigation} = \frac{\text{Cost of irrigation in whole season}}{\text{Grain yield (ton/ha)}} \quad \text{L.E/ton}$$

$$\text{- Economic efficiency for capital investment (\%)} = \frac{\text{Net profit}}{\text{Total cost/ha/season}} \times 100$$

$$\text{- Investment ratio} = \frac{\text{Total price return}}{\text{Total cost/ha/season}}$$

6. Analysis and Discussions (Case Study 1)

Irrigation water applied (IWA)

The amount of irrigation water applied (cm) was measured and estimated for all treatments as average of both seasons as shown in table (7.2) and fig. (7.5). It could be noticed that the amount of applied water was the highest value for traditional method (treatment A), a value of 8143.0 m^3/ha. On the other hand, the lowest value of 3810.0 m^3/ha was recorded from the strip of furrow 160cm (treatment C), while the treatment B recorded 5676.0 m^3/ha. The data revealed that treatments B and C could save about 30.4 and 53.22% of applied irrigation water, respectively compared to treatment A.

Data presented in table (7.2) indicated that T.W.C. 322 cultivar consumed higher quantity of (IWA) than T.W.C. 321 cultivar. Difference was 172 m^3/ha, this means that the two cultivars did not differ clearly from each other.

Water productivity (WP)

Data listed in table (7.2) and figs. (7.4 and7.6), showed that treatment C had the highest value of WP 1.78 kg/m^3 followed by treatment B of 1.17 kg/m^3, while the treatment A recorded the lowest value 0.77 kg/m^3.

The relative increases in WP were 51.95 and 131.17% for treatments B and C compared to treatment A respectively.

Regarding the maize cultivars, it is evident that T.W.C. 322 cultivar has the highest value of WP. The increase of WP was 2.73 % for T.W.C. 322 cultivar compared with T.W.C. 321 cultivar.

Crop data

a. The maize growth

Data presented in table (7.3) indicated that both plant and ear heights were significantly increased when plants were planted with treatment C compared to the other planting methods as shown in the combined analysis.

Data in table (7.3) indicated that plant and ear heights were significantly affected by cultivar. T.W.C. 322 cultivar which gave the highest values of plant and ear heights.

b. Yield components

Combined analysis of variance during the two growth seasons indicated that planting methods had significant influence on all studied characters of yield components (table 7.3). Results indicated that the highest values of ear diameter, ear length, number of ears/plant, ear weight, and 100- kernel weight were recorded for treatment C followed by treatment B, the differences between treatments B and C were insignificant for all aforementioned characters.

Results in table (7.3) revealed that the differences among maize cultivars were significant for all aforementioned characters.

Maize cultivar T.W.C. 322 gave the highest values of ear diameter, ear length, number of ears/plant, ear weight and 100-kernel weight, while the lowest values were resulted from T.W.C. 321 cultivar.

Table (7.2): Effect of planting methods on some indicators of two maize cultivars (as average of two growing seasons)

Treatments	Grain yield (Kg/ha)	Irrigation water applied		Water Save		Water productivity	Increase of Water productivity %
		(cm)	(m^3/ha)	(m^3/ha)	(%)	(kg/m^3)	
Planting method:-							
A: traditional method.	6256.7 a	81.43	8143.0	-	-	0.77	-
B: strips of furrows 80cm.	6643.3 b	56.76	5676.0	2467.0	30.29	1.17	51.95
C: strips of furrows 160cm.	6786.4 c	38.10	3810.0	4333.0	53.21	1.78	131.17
Cultivares:-							
TWC 321	6383.3 a	57.9	5790.0	-	-	1.1	-
TWC 322	6740.9 b	59.62	5962.0	172.0	2.97	1.13	2.73

Table (7.3): Effect of planting methods on some growth characters and yield components of two maize cultivars (combined analysis of two growing seasons)

Treatments	Plant height (cm)	Ear height (cm)	Ear diameter (cm)	Ear length (cm)	Number of ears/plant	Ear weight (gm)	100-kernel weight (gm)
Planting method:-							
A: traditional method	316.0 a	150.6 a	4.90 a	15.4 a	1.07 a	282.6 a	29.15 a
B: Strips of furrows 80 cm	322.0 b	161.0 b	5.58 b	16.6 b	1.19 b	288.4 b	31.60 b
C: Strips of furrows 160 cm	325.0 b	163.0 b	5.60 b	16.9 b	1.28 b	291.5 b	31.83 b
Cultivares:-							
TWC 321	318.0 a	152.6 a	5.16 a	15.9 a	1.12 a	283.0 a	29.3 a
TWC 322	324.1 b	163.3 b	5.56 b	16.7 b	1.24 b	292.0 b	32.42 b

c. Grain yield

Data in table (7.2) show that grain yield was significantly affected by planting methods as average for both seasons (combined analysis). Grain yield was gradually, increased from treatment A to treatment C. The increase percentages in grain yield/fed due to treatments C and B were 6.18 and 8.47%, respectively compared with control (Treatment A).Results found in table (7.2) show that grain yield (kg/ha) of the tested maize cultivars significantly differed from each other. It could be noticed that the differences between the two maize cultivars were slight on this trait. T.W.C. 322 cultivar achieved the highest value of grain yield (kg/ha) and the increase percentage was 5.60 %.

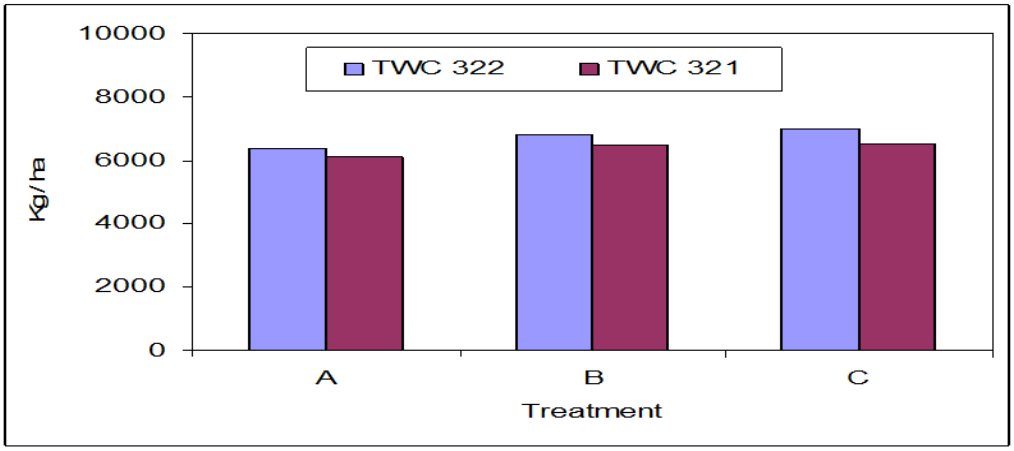

Fig. (7.4). Effect of planting methods on grain yield (kg/ha) of two maize cultivars (average two seasons)

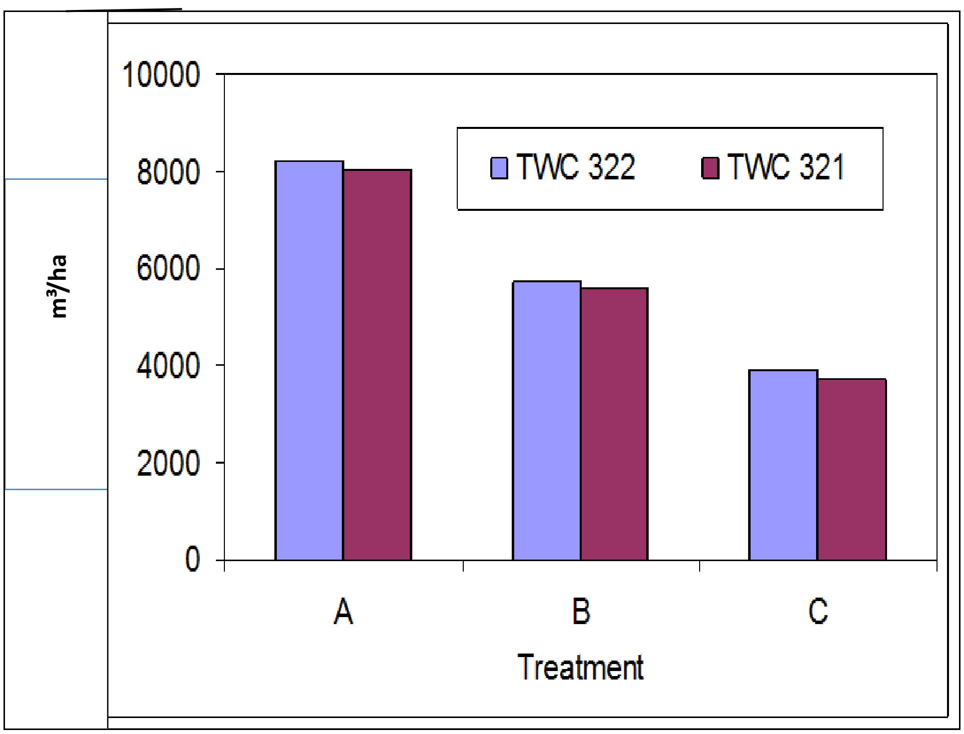

Fig. (7.5). Effect of planting methods on water applied (m^3/ha) of two maize cultivars

(average two seasons)

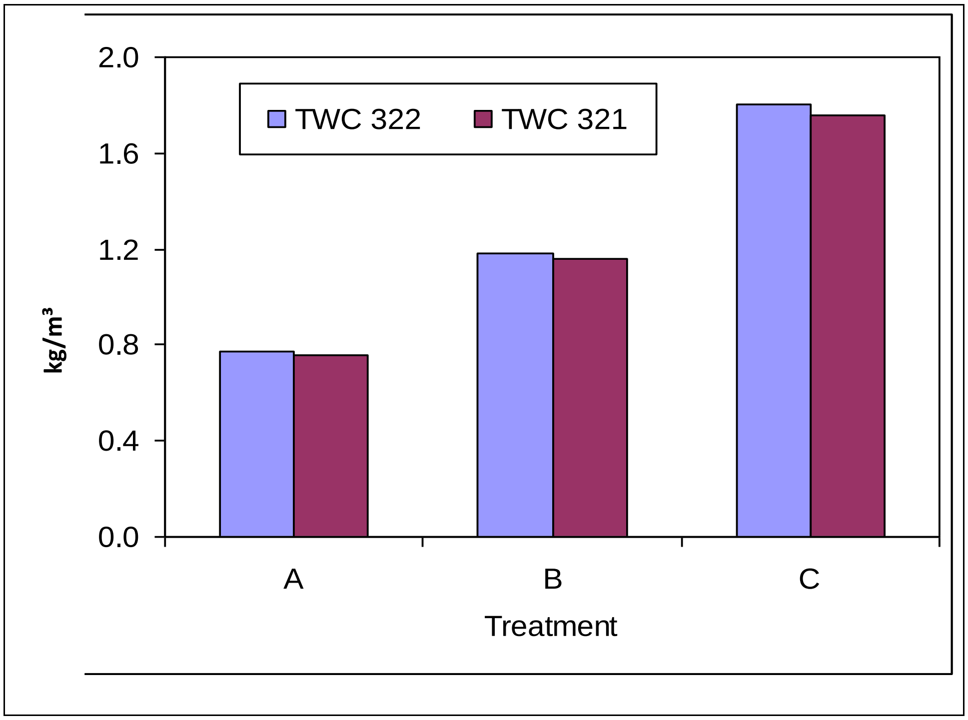

Fig. (7.6). Effect of planting methods on water productivity (kg/m^3) of two maize cultivars

(average two seasons)

7. Discussion

- The results showed that planting of maize crop with traditional method (treatment A) required big quantity of irrigation water more than the new planting method. Generally, increasing amount of irrigation water applied for treatment A compared with new planting method (treatments B and C) may be attributed to the wetted area of treatment A which was more than treatment B or C. Where, in both treatments B and C irrigation water was added to tapes only, in addition to small part for both sides of furrows as a result of water flow in these tapes (bottom of furrows). Accordingly, wetted area of strips of furrows 80 cm and 160 cm width (treatments B and C) was less than traditional method (treatments A) by about 33 and 65 %, respectively. Also number of bottom of furrows or tapes with the treatment C were less than treatment B by 50 %. The results also illustrated that WP was increased with using treatment B and C.

    - The reduction of applied water which valued 30.40 and 53.22% in case of treatments B and C coupled with the increase in grain yield which amounted 6.18 and 8.47%, respectively compared with treatment A, the latter allowed more water to be lost by evaporation and deep percolation.

- Treatment C had the highest value of the relative increase of WP. These results may be due to the best plant distribution and increasing fertilizers use efficiency because the presence of the stand in bottom of furrow (tape).

- In general, increasing values of (WP) for treatments B and C attained to slight increase of grain yield by about 6.16 and 8.45% respectively. Compared with treatment A, this was because of sharp reduction in amounts of irrigation applied water which reached to 30.40 % and 53.22 % for treatments B and C respectively. In addition, irrigated area for treatment B was less than treatment A where irrigation water flow pass through bottom of furrow only (tape). Concerning treatment C, the number of bottoms of furrows (tapes) is less than treatment B, thus the saved water and WP were increased.

Table (7.4). Cost of inputs and out puts items of two maize cultivars under different planting methods as average of both seasons.

Economical items	Characters	Planting methods			
		Unit	A	B	C
List of inputs	Land preparation and cultivation	$/ha	23.81	23.81	23.81
	Seed price	$/ha	19.84	19.84	19.84
	Mineral fertilizers	$/ha	95.24	95.24	95.24
	Pest control	$/ha	11.9	11.9	11.9
	Labor costs	$/ha	31.75	31.75	19.84
	Cost of irrigation in whole season	$/ha	108.57	75.56	50.8
	Harvesting	$/ha	19.84	19.84	19.84
	Land rent	$/ha	396.83	396.83	396.83
	Total cost/ha/season	$/ha	707.78	674.77	638.1
List of outputs	Grain yield	Kg/ha	6256.7	6643.3	6786.6
	Price	$/kg	0.2	0.2	0.2
	Total Price	$/ha	1251.34	1328.66	1357.32
	Net Profit	$/ha	543.56	653.89	719.22
	Cost of irrigation/ton	$	17.35	11.37	7.49
	Economic efficiency for capital investment	%	76.8	96.9	112.71
	Investment ratio	$/$	1.77	1.97	2.13

- With regard to maize plant growth it is also observed that treatment C had the highest value of plant and ear heights. This could be attributed to good utilization of light for treatment C where plants were subjected in two rows in bottom of furrow 35 cm (tape) and the distance between each tape and other were about 125 cm. There upon the plants were strongly grown where treatment C achieved good distribution of irrigation water around the roots where it flow through the tape (bottom of furrow) there at the soil moisture content after each irrigation were reached the optimum level of the soil available water. Consequently the new planting method which used with treatments B and C can be achieved good utilization of irrigation water and nutrients. It could be attributed to the excess wetting of the top of furrow may have resulted in leaching of nutrients from around root zone and bad aeration as result for using big amounts of irrigation water.

- Also, data indicated that decreasing values of ear diameter, ear length, number of ears/plant, ear weight and 100- kernel weight for treatment A may be attributed to the presence of the stand on the top of furrow where irrigation water was adding with big amounts for the soil as the farmers irrigate their fields in the area, leading to bad utilization of irrigation water, bad aeration and leaching of nutrients.

- Concerning grain yield it could be noticed that the decrease in grain yield in treatment A (control) may be due to the excess of applied water which occur partial aeration deficiency in the upper part of root zone. Also, the excess wetting of the top of furrow may have result in leaching out of some nutrients from the root zone. The slight increase in grains yield (6.18%) for treatment B was probably be due to the increase in number of ears/ plant. This was, also, true for treatment C.

- Regarding, the economic evaluation, (table 7.4) it could be noticed that treatment C had the highest value of net profit because it was less costs of irrigation in whole season and labor costs. On the other hand, it gave the high value of grain yield and consequently decreases of costs of irrigation/ton and increase of economic efficiency for capital investment and investment ratio compared to the other treatments.

- Generally, in this study the new planting methods for maize (strip of furrow 80 cm and 160 cm) were always better than traditional method in reduction of IWA and costs, while it increase WP, maize growth, yield components and grain yield, because planting maize in strips of furrows, (According to method's of Atta and Ibrahim, 2005), perhaps made a good advantages and important properties such as:

- Good distribution of irrigation water around roots.
- The wetted area was less than traditional method.
- Water saving,
- Utilization of light was better.
- Good plant distribution and increasing fertilizers use efficiency,
- Increasing grain yield,
- Raising water productivity and
- The costs were less than traditional method.

Thus, the yield components and grain yield were the highest treatment C followed by treatment B when comparing with treatment A.

In conclusion, the new planting method was suitable for increasing maize growth, increasing grain yield, water saving, water productivity and decreasing of irrigation cost.

7. Impact of the Expansion of the Innovative Method

As a national goal, by applying this innovative method all over Egypt for the maize cropped area it means that, about 4.0 billion cubic meter of irrigation water could be saved from cultivating one million hectare of maize. This amount of water saving can be used for horizontal expansion of new lands.

Photo 3: strip 160 cm spacing (bottom of furrow)

Photo 4: furrow 80 cm spacing (traditional method)

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Case 2(A): Water Saving for Rice Crop

By: Dr. Sayed Abdel Hafez* (Review study)

The traditional continuous flooding irrigation method for rice uses a large amount of water. Since the 1980s the lack of water resources has become an important problem and the water-saving irrigation method has been tested and applied in northern Egypt. The basic: features of these new methods are: sprinkler irrigation method, irrigation intervals, field submergence depths, and methods of rice cultivation. Based on the analysis of observed data from experimental stations and from some typical areas in northern Egypt, quantitative results of the environmental impact observed from spreading the water-saving irrigation method for rice is reviewed.

1. Water-saving Irrigation Methods

1.1 Sprinkler irrigation system

Abd El-Hafez et al., (2001) evaluated two methods of rice planting grown under sprinkler irrigation system at North Delta Egypt, and they found that watering with 120% of ET_o significantly increased number of tillers/m^2 and grain yield by 30.42 and 18.88% over the treatment which irrigated with 100% of ET_o. Mean values of irrigation water applied reached 129.66 cm under sprinkler system, whereas it was 174.06cm the flooding system. Average of water saving under sprinkler irrigation system was 23.3% compared to the flooding method.

Values of field water use efficiency (kg grain/cm of water applied) under sprinkler irrigation system surpassed flooding method by 14.43%.

Transplanting method under sprinkler irrigation system significantly exceeded drill method in panicle weight, number of filling grains and grain yield by 68.0%, 80.03 and 27.53%, respectively. Also transplanting method achieved the highest value of field water use efficiency and proved its superiority over used drill under sprinkler irrigation system.

Mahrous et al., (1984) evaluated sprinkler irrigated rice in North Delta, and they found that watering every two days with 140% of reference evapotranspiration using dry seeds, significantly exceeded the other treatments of watering every day with 140% of reference evapotranspiration in terms of number of grains/ panicle, number of filling grains, grain yield (kg/fed).

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They also revealed that irrigation water applied under sprinkler irrigation system was 5210.36 m^3/feddan, whereas it was 7500 m^3/feddan under flooding method. It means that sprinkler irrigation saved about 43.9%.

El-Mowelhi et al., (1999b) evaluate the performance of some rice cultivars under sprinkler irrigation system. And they found that rice cv. Giza 176 significantly exceeded in plant height, panicle weight, number of grains/panicle and number of filling grains/panicle. On the other hand, rice IET 1444 significantly superior to other cultivars (Giza 176, Giza 178 Sakha 101, Sakha 102) under study in flag leaf area, number of panicle/plant, grain yield per fed. And water use efficiency (0.58 kg grain yield/m^3) of water applied. And the gross irrigation water applied amounted 5266.8 m^3/fed.

1.2 Irrigation intervals

Mahrous et al. (1984) found that total rice water requirements were 199, 165 and 141cm when irrigation intervals were 4, 6 and 8 days, respectively. El-Refai (1974) found that the yield of rice increased with increasing water up to 8000m^3/fed. While increasing the irrigation level beyond that insignificantly lowered the yield. Nour (1989) reported that the mean total water requirements for transplanting rice were 8769, 5983 and 4817 m^3/fed, for 4, 8, 12 days irrigation intervals, respectively. El-Refai (2002) revealed that total water used by rice were 13408, 12439.5, 11877.2. and 11066.3 m^3/ha for irrigation treatments i.e. alternate 4-day on+6 days off, alternate 4-day on + 8 day off, alternate 4-day on + 10 day off and alternate 4-day on + 12 day off respectively.

1.3 Field submergence depths

Medium and long duration varieties are normally grown under soil submergence. Studies show that submergence of the crop is beneficial and a depth of submergence ranging from 5 to 7 cm is optimum. Depth of standing water above 7cm is of no advantage for most of the tall indicia varieties and is harmful to dwarf indicia varieties (Dastane et al., 1971, Lenka and Biol, 1972 El-Mowelhi et al. (1984) reported that the irrigation depths exerted insignificant effect on rice grain yield indicating that increase in water depth over 5cm was a water waste.

Deeper standing water during the initial growth period has proved deleterious. Submergence of the field up to a depth of 8cm during the pre-flowering stage and a state of dryness during the post-flowering stage was useful for increased yields (Datta and Sen, 1963). Mandal and Majumdar (1983) reported that soil submergence of 3 to 5cm depth of water from transplanting to flowering and soil saturation after that was the best for yields. However, they stated that soil saturation throughout the crop period was advantageous considering the huge savings of water.

Intermittent soil submergence after the establishment stage of the crop saves a considerable amount of water without affecting the yield. Parrihar et al. (1995) observed that rice crop could be subjected to 7 days drying period after disappearance of 7cm pounded water with no significant yield reduction and that saved 45% irrigation water compared to 1 day drying period.

A rice crop of about 150 days duration requires water amounting to 64 cm for raising the nursery, 102 cm for growth from planting to flowering and a further amount of 25 cm for ripening making the total to 190 cm (Ramiah and Vacchani, 1951). A great part of the water requirement of rice constitutes the water lost through deep percolation. Vamadevan and Dastane (1967) stated that, 120 cm of water was lost through deep percolation and 48 cm only was used by the crop as consumptive use. The percolation loss was greatly reduced under condition of soil saturation more than under continuous soil submergence.

As considerable amount of water is lost from rice fields through percolation, attempts have been made to advice ways to reduce or prevent water loss through percolation.

1.4 Methods of cultivation

Transplanting method resulted in the highest grain yield and proved its superiority over the other treatments i.e. broadcasting and seed drill. It also saved irrigation water and achieved the highest values of water use efficiency (El-Mowelhi et al.1995).

El-Gidali and Mahrous (1970) indicated that the transplanting method increased rice grain yield by 23.6% and saved about 18.7% of irrigation water and gave the highest values of water use efficiency, and reported that hand transplanting gave the highest revenue followed by seed drill and mechanical transplanting.

2. Water Use Efficiency

The benefit of applied water through economic crop production has to be evaluated and determined. It is very important in crop production and irrigation water management. In areas where water is scarce, crop producing more per unit for water rather than giving higher total yields should have the reference in the cropping system.

El-Mowelhi et al., (1999a) pointed out that flooding irrigation method reduced field water use efficiency (kg grain yield/m^3 of water applied) by 20.3% as compared to sprinkler method.

Continuous flooding produced the highest grain yield followed by irrigation every 6 days, while the lowest grain yield was obtained by irrigation every 12 days. Increasing the irrigation intervals beyond 3 days, yield was reduced and the reduction was varied according to the cultivars (National Rice Program Workshop 2005).

The amount of water saved due to increasing the irrigation intervals compared to continuous flooding (3-days) ranged from 8.32% with 6-days to 27.49% with 12-days. Water use efficiency of irrigation every 6 or 9 days are considered the best WUE for most cultivars compared with other irrigation treatments. Continues saturation saved water by 20.9% with yield reduction about 3.98% when medium duration variety was used, while the water saved by about 31.43% with yield reduction 3.57%when short duration varieties were used. Also, the irrigation every 4 days caused an increase in water use efficiency by about 86% (National Rice Program Workshop, 2005). The maximum of rice yield potential was found to exist when soil is maintained under flooding or saturation conditions (Abd El-Hafez, 1982; Mahrous et al., 1984).

Continuous flooding resulted in higher rice yield than intermittent flooding, while intermittent flooding raised the water use efficiency from 22 to 40% over that of the continuous flooding (Genaidy, 1989). Water use efficiency increased by 0.438, 0.566 and 0.649 kg grains/m^3 of water applied as the irrigation interval increased from 4 to 8 and 12 days respectively (Nour, 1989), Nour and Mahrous (1994) found that continuous saturation recorded the highest water use efficiency and water saves compared to irrigation every 8 days. El-Refaee (1997) found that irrigation every 6 days recorded the highest value of water use efficiency compared with irrigation every 9, 12 days and the continuous flooding as well. El-Refaee (2002) showed that irrigation treatment which was 4-days on +8-days off recorded the highest water used efficiency (WUE) and minimum yield reduction with higher water saved percent compared to other treatments (4-days) on + (6 days) off, 4- days on + 10 days off, and 4-days on +12 days off).

3. Yield and Irrigation Deficit

Plant height, 100-grain weight and rice grain yield tended to decrease as the irrigation interval prolonged from 6 to 8 days: Mahrous et al., (1984), (Nour 1989) showed that number of panicles/m^2, panicle weight, weight, number of spikes/panicle, panicle length and grain and straw yields decreased as the irrigation intervals increased from 4 to 12 days, but there was no significant difference between 4 and 8 days interval in the yield Nour (1994) pointed out that increasing irrigation interval longer than 6 days significantly decreased plant height, biomass production, rice grain yield as well as yield components. El-Wahisy and Abdel Hafez (1997) found that plant height, number of panicles/hill, panicle length, number of spikelets/panicle; grain and straw yields were decreased as irrigation intervals increased up to 14 days.

4. Critical Period of Water Need

Critical stages of water needs for rice are the tiller initiation, primordium initiation and flowering stages (Ghosh and Bhatacharje, 1959, Datta and Sen, 1963, Dastane et al., 1971, Choudhury and Pandey, 1968). The most critical stage of growth was the panicle initiation, water stress at this particular stage resulted in 5% yield reduction compared with continuous irrigation (Hamissa et al., 1988). The flowering stage considered as the most critical stage of water need. Lack of adequate water at the critical stages reduces the yield even up to 50 per cent. The periods of high water needs are the first 10 days during the grain formation stage (Singh et al., 1935). Water requirements gradually increase from the early stage of the crop to flowering and the maximum is reached just before flowering. Soon after flowering there is a great decrease in water requirement (Narsingha Rao, 1951). For uniform maturity of the crop and to facilitate harvesting irrigation should be stopped after the grain hardening stage.

A study showed that termination of irrigation 14 to 17 days before the harvest resulted to a uniform maturity of the crop and economized 16cm of irrigation water, while suspension of irrigation 3 weeks before the harvest saved 22 cm of water. In the later case, there was a marginal decrease of only 200 kg grains per hectare.

This efficiency is determined to evaluate the irrigation practices in a farm. It accounts for loss of water by seepage in the supply channel, deep percolation and occasionally run-off occurring in fields. The deep percolation loss in wet rice is exceptionally high and range from 38.3 per cent to as much as 80 per cent of the water applied in various soils (Mandal and Majumdar, 1983). The efficiency may be very low in a hardly managed farm and 75 per cent in a well-managed farm. There is a tendency of farmers to frequently irrigate and give excess water to other crops when the supply of water is abundant. Besides, absent of water measuring devices and ignorance of farmers is a deciding the time of irrigation and quantity of water required for irrigation often pose problems.

Conclusion

In Egypt, the use of the water-saving irrigation methods for rice is increasing rapidly year after year. A positive environmental impact is obtained by adopting these new irrigation techniques. Therefore, the water-saving irrigation methods for rice should be more widely used because of its potential for saving water, increasing rice yield, and improving the water and soil environment conditions in rice irrigation districts.

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Case study 2(B) Water Saving for Effective Irrigation Management in Egyptian Rice Cultivation.

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1. Introduction

Rice normally needs (under traditional methods in Egypt) a water application of about 2000 mm; an amount much higher than other crops. About 11 billion m^3 of irrigation water are being used in rice production in the Nile Delta. This amount represents about 20% of the whole quantity of irrigation water used in agriculture (55.5 billion^3 /year). Particularly water consumed under the conventional irrigation method is considered. Saving water is becoming a decisive reason for agricultural expansion. Limited water supplies and the remarkable increase in population (85 million capita, FAO, 2013) should force researchers to find ways to save more water without a significant fall in yield. Great efforts should be made with water management practices to find ways to save more irrigation water.

Water saving strategies in agriculture are not limited to irrigation practices. They extend into the other areas affecting on farm water application including varieties, cultivation methods and benefits of land leveling (Ichino & Kasuya, 1998; Hama et al., 2011; De Miguel et al., 2013). Water-saving methods are needed in rice to mitigate the effect of a lack of water, to increase water productivity, and to safeguard food security. At the same time, the salinity in the Northern Delta must be controlled. This article aims to combine exercises of various water-saving technologies for rice in Egypt. First, it will produce an inventory, description, and a comparative analysis of farm-level water-saving technologies already done as individual research. Second, it will study technologies in detail and survey their adoption and impact on the saving of irrigation water. Finally, some scenarios suggestions may help in irrigation management and water saving.

2. Materials and Methods

The study depended on published and unpublished data for the period until 2012, issued by the Ministry of Agriculture and Land Reclamation (MALR); Ministry of Water Resources and Irrigation (MWRI); Agricultural Research Center (Rice Research Program); the National Rice Program at Rice Research and Training Center (RRTC); and Food and Agriculture Organization of the Unit Nations (FAO). The influence of irrigation water saving in rice production was evaluated. The yield needed to meet the projected 2030 demand for rice was calculated for self-sufficiency.

This demand was estimated from past trends in rice consumption per person. Legally and illegally cultivated rice areas and their salinity levels were surveyed and calculated. Finally, a plan was suggested and designed for the future to help in irrigation management and water saving.

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Before improvement **After improvemen**

Fig. (7.7)Improved branch canal (Mesqa).

3. Results

Several techniques have been developed for water management to improve water-use efficiency. For crop irrigation, ideal water efficiency means reducing losses because of evaporation, runoff or subsurface drainage while increasing production. (Atta,2008).

The Egyptian government has done successful efforts to develop the use of water resources. That strategy includes strengthening the awareness and community of people to control the use of irrigation water. It helps to save 10–15% of irrigation water and increase the crop production by 15–20%. This strategy has led to a plan for developing irrigation systems in several ways. The authors divided these ways into off-farm and on-farm improvements.

3.1 Off-farm irrigation water management practices

To achieve on-time water deliveries, Egypt started a national program to improve the main delivery system (Irrigation Improvement Project, IIP). Irrigation canals are classified into main canals (first level canals), branch canals (second level canals), and distribution canals (Mesqas, or third level canals which serving an area up to 50 ha). Improving the main delivery system through a rehabilitation of water structures such as intakes and tail escapes lessens water losses from canals end to drains. Replacement of the old structures with new ones with radial gates to provide automatic control for the downstream water levels to cope with farmers' demand and abstraction. Furthermore, turnouts and off takes are also planned for installation along the branch canals such as facilities at the head of each Mesqa, pumps, and pump sumps.

Improvement of Mesqa makes up the major part of the improving irrigation performance. It includes replacing the existing Mesqa with improved one. The old Mesqa is usually an earthen and low level ditch with no organized water withdrawals through multiple pumping and lifting points along its length. Two types were recommended for improving the old Mesqa, open elevated Mesqa and buried low-pressure pipe. Normal water level in the elevated Mesqa was set to allow gravity flow to the field at 15 cm above the field level. Alternatives for elevated Mesqa include a rectangular concrete cast-in place section and precast concrete.

The IIP is concerned with improving the existing irrigation system in Egypt over a total area of 10^6ha ≈ one million ha in the northern part of the Nile Delta. The overall objectives of the project were improving irrigation infrastructure, promoting more equable distribution of water, improving on-farm water management, minimizing different irrigation water losses and increasing water-use efficiency for different crops. The different field data were collected by the field staff day after day in the project’s area. Data analysis was done for the rice cultivation area. Results showed increasing of rice crop yield of 11.4%. This increase due to the good conditions of water availability by the equity distributing between the head and tail of the Mesqa. Meanwhile the irrigation time for rice decreased in all Mesqas. The irrigation water was decreased on an average of 15.55%. In other words, since the crop yield increased and the irrigation water decreased, the water use efficiency increased.

According to the previous data, the irrigation water decreased from 20,000 to 16,900 m^3/ha for rice production.

3.2 On-farm irrigation water management practices

Several field experiments were conducted to rationalize water use. These experiments included:

- Substituting the long-duration varieties with short-duration varieties,
- Using dry rice
- Using different planting methods with combining land preparations.

3.2.1. Shorter season varieties

The rice working group developed many rice varieties which express to reduce water consumption (Giza 177 and Sakha 102). The varieties reduce the time from planting to harvest by 40 days (120 days compared to 160 days for current longer-season varieties). A pilot program involved a package of agricultural practices and fulfilled water delivery for short-duration rice varieties until the rice-growing season of 1997 (RRTC 1998). Measured reduction of water delivery to the canal for the period from May 1 to October 31 was estimated at $3\times10^3 m^3$/ha of applied water. That means when the short-duration varieties applied on all rice growing areas within the next two to three years to the 625×10^3 ha of rice, a decrease of about 2 billion m^3 of applied water could be expected.

During the 2000 summer season (after three years), it was noted that around 8×10^5 ha of rice was being cultivated because of the high yield and low applied water. However, all water savings because of substituting short duration varieties are exhausted (RRTC 2001) table (7.5).

In summary, cultivating short-season rice saves about 18% (from 16,900 to 13,900 m^3/ha) of the water deliveries needed for long-season rice.

Table (7.5) Areas of rice cultivations in for all regions

Region	Planed area (ha)*	Actual area (ha)	Increasing (ha)	% of increasing
Legal	446,000	641,000	195,000	43.7%
Illegal	0	225,000	225,000	
Total	446,000	866,000	420,000	94.2%

*The area decided by MWRI and MALR (2012).

3.2.2 Land leveling and transplanting

Soil dry leveling by laser plays an important role in rice planting. It saves water by 25% (Badawi and Ghanem, 2007) because of the controlled water distribution in rice fields. This improved rice productivity compared with uncontrolled water distribution. On the other hand, using mechanical transplanting with land leveling could save about 3–5% water, which is used in seedling stage in the nurseries (Khattak et al., 2006).

In summary, mechanization management in soil preparation with transplanting could decrease the applied irrigation water by 29% (from 13,900 to 10,000 m^3/ha) and increase water use efficiency.

3.2.3 Planting methods

This method depends on reducing the irrigated area by the land division into furrows with 45 cm top and 35 cm bottom. The seedlings are transplanted in hills

(4–5 plants) 10 cm at the bottom of the furrow with using the same plant density (25 hills/m^2) as recommended into two rows of plants. Planting irrigation was given with enough to reach puddling. Then the next irrigation were given for bottom only with a depth of 7 cm. Therefore, the flood area was less and thus increased water saving about 30–40%. This new method increased irrigation application efficiency and water productivity; however, it decreased percolation losses and decreased evaporation (Atta et al., 2006; Atta, 2008).

The results showed the applied water was reduced from 13,900 to 9000 m^3/ha with water saving about 4900 m^3/ha (35%). The comparison between the new and the traditional rice cultivation methods show the production increased about 5% and the water use efficiency can be reached to 75%.

3.2.4 Dry rice (aerobic)

A breeding rice program was done in RRTC for transferring prescription drought tolerance to some local high-yield and short season varieties. The varieties obtained were evaluated for three years, 2007–2010, as preliminary experiments under drought conditions (12–15-day irrigation intervals). The crop has reached those breeds 10 t/ha providing about 40% (13,900–8300 m^3/ha) of irrigation water comparing same varieties cultivated under conditions of continuous flood (RRTC, 2010). Another experiment at the department of genetics at the faculty of agriculture, Zagazig university, developed types of rice with standing drought. Two varieties were reached “Oraby 1 and 2”, which consumes 50% of the water when grown in furrows compared to traditional rice varieties. Evaluating those breeds helped advances in the final stages of registration as new varieties consume less amounts of irrigation water ($7\times10^3 m^3$/ha) without affecting productivity (Soliman and Saaid, 2010).

3.2.5 The hybrid rice

Egypt located on the throne of rice productivity in the world (10 t/ha) and it is difficult to increase productivity more than that in the conventional varieties amended. The rice program has already achieved distinct high-yielding hybrids that meet all purposes, including hybrids bear conditions and lack of water and climate change (Ebaid and El-Mowafi, 2005; Gorgy, 2007). According to(El-Mowafi 2010), Sakha “2034” has been registered to become the first hybrid rice class called Egyptian “1”. This strain gives 14 t/ha with medium duration season not exceeding 130 days, is resistant to diseases and can be cultivated in all fertile and salt soils, while in addition having more than 20% water savings. Furthermore, tests were completed for the hybrid Sakha “2946” to be registered as the Egyptian hybrid “2”. This strain gives the highest productivity with 16 t/ha.

3.2.6 Cultivating high-value crops instead of rice

One may conclude that there are positive results on water savings if a farmer grows high value crops such as yellow corn, sesame or vegetables instead of growing rice. According to the field records, the average water need for yellow corn and sesame were 4750 (furrow irrigation using gated pipes) and 3240 m^3/ha, respectively compared to 8000 m^3/ha for rice. Similar results were seen for income per ha for yellow corn and sesame where the average net income is 8000 LE (Egyptian Pound) compared to rice where it is about 5000 LE according to year 2010 prices (USAID, 2011) (1 US Dollar = about 7 LE).

4. Discussion

There is a clear constraint on lessening irrigation water in Egypt based on the need to control salinity in the Northern Delta. The salty aquifer which underlies the Northern Delta will cause soil salinity problems when the hydraulic pressure gradient allows because of upward migration. Periodic flushing with enough fresh water is required to reduce this upward migration. There is evidence that rice cultivation has improved some of the relatively salty soils in the Northern Delta. So rice cultivation is an important approach to conserve soil fertility and to reduce the salinity hazard.

The Northern Delta salinity problem has to be considered for any irrigation management method to reduce water consumption. Also, it should be reconsidered how much rice should be legally grown in Egypt bearing in mind future needs and constraints. According to the discussed and analyzed data, the actual cultivated rice area increased by 94% more than the legal area (Table 7.5). This area produced more than 8 million tons while the maximum local consumption is 5 million tons (Othman et al., 2011). The expected population will be 100 million by the year 2030 (FAO, 2013), meaning the local consumption will increase to 6.1 million tons.

Two scenarios were suggested, and irrigation water saving was calculated as follows:

1.Water savings if rice is cultivated according to the actual area in Table (7.5)

This scenario suggested no changes in the rice area. According to MWRI and MALR reports (2012), the saline soil area in the Northern Delta is about 1.5×10^5 ha. To be on the safe side, the area in this scenario calculated as 2×10^5 ha (Fig. 7.8).

The total applied irrigation in the Northern Delta area is calculated at 1.66 billion m^3 while it was 4.66 billion m^3 for the other regions. So the irrigation water for the whole rice area will be about 6.32 billion m^3, leading to a 43% water saving (11 billion m^3 in traditional cultivation). On the other hand, total rice production will be more than 9 million tons.

2. Water savings from converting 333×10^3 ha of rice cultivation to other crops

In this scenario, the government has to pay more attention to cultivating alternative crops that not only use less water, but also give significantly higher returns, and in this way increase the added value per unit of water consumed. So if a plan is designed to cultivate about 333×10^3 ha of high value crops instead of rice (50% of rice area outside North Delta), the used water will be about 5.32 billion m^3, leads to 52% water savings (Fig.7.9). The total rice production will be about 6 million t/year (4.2 million tons milled rice) which will be enough for consumption with the future needs (until the year 2030). Also, more than one billion LE returns from the high value crops (yellow corn and sesame) could be doubled if other high value crops are used (mint, chamomile, basil, golden sesame and marjoram).

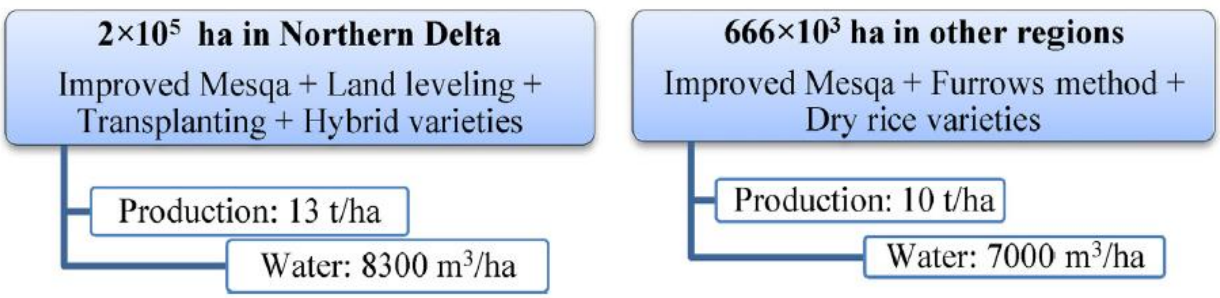

Fig. (7.8)Schematic diagram for the first scenario (no changing in the rice area).

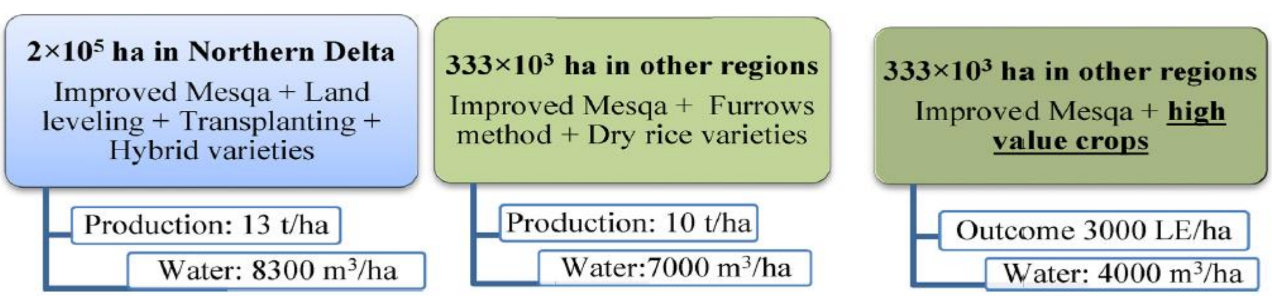

Fig.(7.9) Schematic diagram for the second scenario (38% decreases in the rice area)

5. Conclusion

A serious cultural problem dominates in the minds and actions of the Egyptian farmers' "culture of abundance of water". They deal with water as if it was inexhaustible resource, are wasteful in irrigation and non-compliant with regulations for the voracious water crops such as rice. Every year Egypt exports thousands tons of rice, and in fact we export water, where it is known that rice crops need much water, even with new varieties that consume less water than older varieties. Egyptian rice production is more than domestic consumption, and we export to countries without the scarcity of water. So the decision to decrease the current rice area gradually will be useful for Egyptian agriculture. It will contribute to a large extent in providing water and increasing other crop areas like corn. The study suggested two scenarios for the current and future rice cultivation areas.

The first scenario depends on redistributing the current area of the rice, where 23% is to cover all saline areas in North Delta (2×10^5 ha) using "improved Mesqa + land leveling

+ transplanting + hybrid varieties". The other 77% of rice area (666×10^3ha) uses improved Mesqa + furrows method + dry rice varieties". This scenario could help to save irrigation water by 43% of the currently applied water. The second scenario depends on the rice area could be reduced by 33×10^4 ha (38%) and cultivate with the high value crops like yellow corn and sesame. In that case the applied water can be reduced by 52% by increasing in the net return by 1 billion LE.

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Case study 2 (C): Innovative Method of Water Saving in Rice Fields

*By :Dr. Yosri Atta**

1. Introduction

Rice is one of the most important crops in Egypt providing a good source of income. Rice remains an exception such that the areas entitled to cultivate rice are defined by the Ministry of Water Resources and Irrigation (MWRI) to about 46000 hectares per year.

Irrigation management under old lands conditions which irrigated by surface irrigation method is very important to improve production and water saving. Increasing water use efficiency of rice, can be improved without additional costs to the farmers and consequently water save. So, saving water is necessary to face the water shortage. Such saving for irrigation water of rice is likely to be achieved by using a new planting and irrigation method with high potential for water saving.

This new method was performed in order to seek a possibility of growing rice on strips in order to decrease the amount of irrigation water as well as increasing water productivity.

2.Background

The traditional method for rice cultivation require that rice seeds be first soaked in sufficient water for 48 hr and then incubated for 24 hr to enhance the germination. Then after that, it was handled broadcasted.

Field preparation and nursery practices performed according to the traditional local management. 30 days old seedlings were transferred from the nursery and transplanted in the permanent field after puddling. The field is usually divided into basins. Transplanting of seedlings rice on flat at the hills (4-5 plants) distance of 20 x 20 cm to give the rate of (25 hills/m^2) as recommended. All other cultural practices for rice were followed; the irrigation of rice crop during growing season was applied with 10 cm. The farmers got used to over irrigate their fields where losses of water are great. Hence decreasing of water productivity, therefore it is necessary to find out a new planting method and a new surface irrigation technique.

There are many trials to estimate the amount of water used for land preparation for both nursery and permanent field, raising nursery for 30 days and the amount used during transplanting stage. This amount was estimated of 3983 m^3/ha.

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*This study was made by: Dr. Yosri Attia (2004-2005) Professor, Irrigation Management Institute, NWRC, Cairo, Egypt.

Some other researchers Nour and Mahrous (1994) estimated this amount of water and found it 4602 m^3/ha, Nour et al (1996) found it 4790 m^3/ha, Sorour et al (1998) found it 4495 m^3/ha and Atta (2005) found it 4476 m^3/ha.

Many investigators studied also the water requirements of rice at continuous flooding in the whole seasion, Abou-Soliman et al (1990) gave a range of 16190-21428 m^3/ha, Nour and Mahrous (1994) found this amount of water was 19152 m^3/ha and Atta (2005) found it 14870 m^3/ha.

3. Description of the Innovative Method

This method depends on reducing irrigated area by land preparation into furrows. Top of furrow was named (border) and bottom of furrow was named (tape) fig. (7. 2c.1), every border and tape named (strip). The seedlings were transplanted in bottom of furrow (tape) with using the same plant density as recommended into two rows of plants according to strip width. Irrigation was given with enough amount for reaching to puddeling then, the next irrigations were given for taps only with depth of 7cm.

Accordingly flooding area was less and consequently increased water saving by about 40%.Using this new method increased irrigation application efficiency and water productivity. In addition to, it decreased percolation losses and decreased evaporation. The innovative method of rice cultivation (on strips) was applied in farmers fields on five governorates under different soil and climate conditions in Egypt in 150 hectares. This method aimed to seek the possibility of growing rice in the bottom of furrows (strips) in order to increase water use efficiency of the cultivar Sakha 104 with cropping period (135 days)

Photo: 7.2.c1

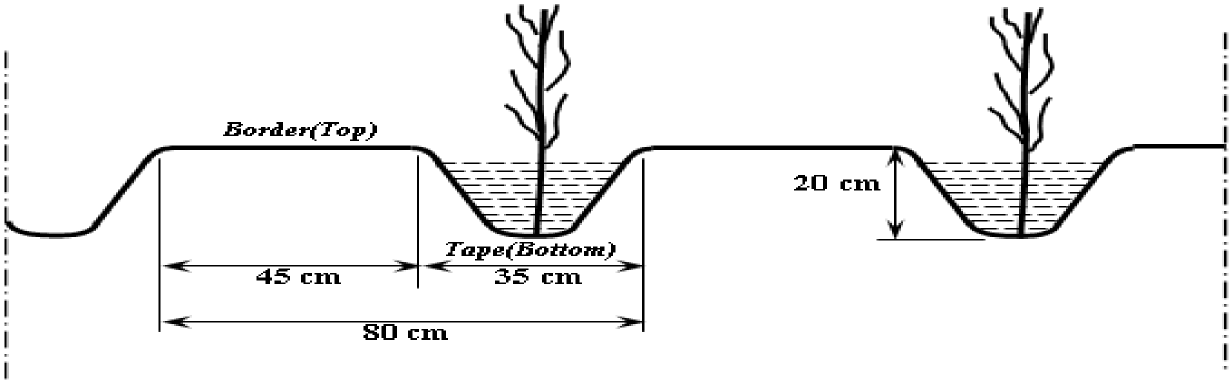
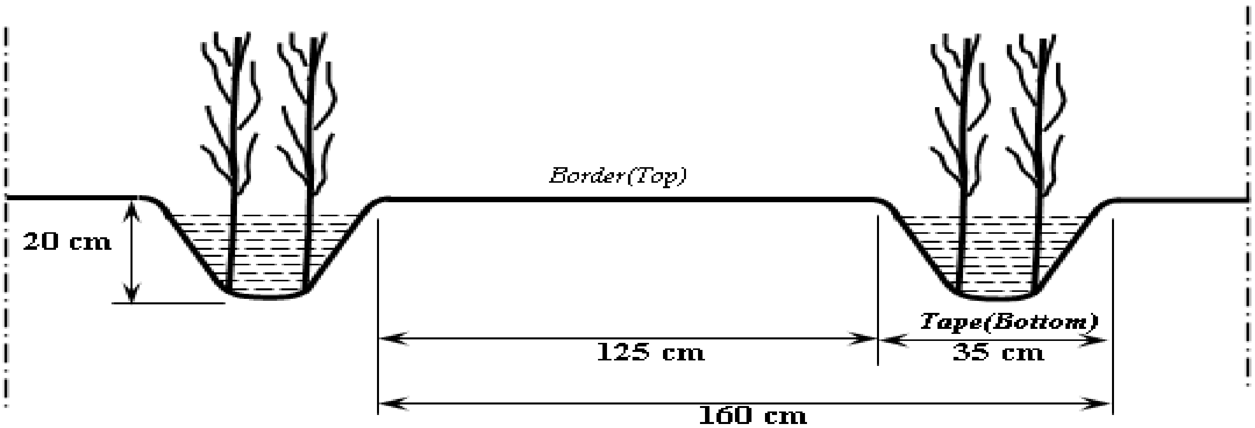


Fig.(7.2c.1) Cross section indicating strips of furrow 80cm width with row of plants in bottom of furrow (Tape) 22cm in between to give 57140 plant/ha.



Fig(7.2.c2) Cross section indicating strips of furrows 160 cm width with two rows of plants in bottom of furrow (Tape) 22 cm in between to give 57140 plant/ha.

Photo: (7.2.c2) Traditional method

Photo: (7.2.c3) Innovation method

Planting methods (M): two planting methods were followed in the permanent field:

M_1: Traditional transplanting(Photo 7.2.c2): Transplanting of seedlings rice on flat at the hills (4-5 plants) distance of 20 ×20 cm. to give the rate of (25 hills/m^2).

M_2: Transplanting in strips of furrows 80 cm. wide: (Photo 7.2.c3): (Top of furrow 45cm. (border) and 35 cm. for bottom tape) Seedlings were transplanting in hills (4-5 plants) 10 cm. apart in the two rows on the bottoms of furrows (tapes) keeping population the same as in the traditional method (25 hills/m^2) as recommended.

Conservation of plant density

Using this method, it achieved new plants distribution as recommended plant density is (25 hills/m^2) and in order to survive this density, the plant density can be calculated for example as follows:

Furrow with long 10 m and wide at 0.8 m.

Total area = 10 x 0.8 = 8 m^2

Number of hills = 8 x 25 = 200 hills

Number of hills in each row = 200/2 = 100 hills

Distance between hills = 10/100 = 0.1 m

And consequently, number of hills per unit area is equal for both new and traditional methods.

Generally in this study the new planting method for rice (strip of furrow 80 cm) was always better than traditional method in reduction of irrigation water applied and costs while it increase water productivity and grain yield because planting rice on strips perhaps resulted in:

- Good distribution of plants.
- Less flooding area.
- Water saving 30%-40%.
- Raising water productivity.
- Increasing fertilizers use efficiency.

This innovative method has been conducted in 2002 on small research area as an experimental work. After that, through years of 2003 till 2005, whereas the experiments showed good results, the Ministry of Water Resources and Irrigation co-operated with the Water Management Research Institute of the MWRI to extend this innovative method on different governorates covering all climate and soil conditions in Egypt. These governorates were located on different regions (North Delta, Middle Delta, West Delta and East Delta). This extension work aimed to convince the farmers by using this new method in order to save water. During these extension years farmers were convinced by this method. The cultivated areas reached 50 hectares distributed on different sites.

This method has been used through years 2006 and 2007 on large scale on five regions including Fayoum Governorate, Middle Egypt on an area about 150 hectares.

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Case study 3: Water Saving in Wheat Fields Applying Deficit Irrigation

By: A.Swelam1 and Atta[2]

1. Introduction

Wheat is one of the most important cereal crops in Egypt and in the world. In Egypt the local production of wheat is not sufficient to meet the annual demand of the increasing population. Water management with high yielding varieties is considered as the top important factors affecting wheat production. Many investigators studied the effect of irrigation treatments on wheat yield, yield components, water requirements, water consumptive use and water productivity. In this regard, Melvin et al., (2007) reported that at the research level deficit irrigation strategies proved to be valuable water conserving practices and it should be applied as effective strategy at the large scale level in farmers' fields. Abd El-Ghany, H.M., et al., (2012) studied the effect of deficit irrigation on wheat in Middle Delta and they found that the water deficit imposed at the tillering stage reduced significantly the growth traits, while yield and its components were affected by water scarcity during flowering stage more than it's affected during tillering growth stage. The objective of this Research is to study the effect of deficit irrigations on water consumption use and yield of wheat crop.

2. Experimental program

Two field experiments were conducted during three successive seasons (2007/08 to 2009/10) at Zankalon Water Research Station, Water Management Research Institute of the NWRC. This site represents the area and conditions of East Nile Delta. Soil physical and chemical properties are shown in table (7.c3.1).

Table (7.c3.1) Soil Physical and Chemical properties of the experimental site

Depth (cm)	Sand %	Silt %	Clay %	Texture	Bulk density (g cm^{-3})	Field capacity (%)	Wilting point (%)	Available water (%)	E.C (dS m^{-1})	pH
0-15	25.80	29.69	44.51	Clay	1.25	43.51	23.55	19.96	1.40	8.1
15-30	25.12	31.38	43.50		1.27	40.50	21.06	19.44	1.22	8.0
30-45	26.00	32.20	41.80		1.35	37.12	17.59	19.53	1.25	8.0
45-60	26.70	33.00	40.30		1.41	36.27	16.64	19.64	1.05	8.0
Average	25.91	31.57	42.50		1.32	39.35	19.71	19.64	1.23	8.03

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*A.Swelam[1]&Atta[2]: [1]Nile Valley and Sub-Saharan Africa Regional Program, ICARDA, Egypt,[2] Water Management and Irrigation System Research Institute , National Water Research Center , Egypt .

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Three seasons, respectively. The preceding crop was rice in the three seasons.

Recommended cultural practices for wheat plants were applied. All plots received the same level of NPK. Nitrogen was applied as (ammonium nitrate 33.5 % N) at the rate of 178 kg/ha in two doses, one third was added at planting and the other two thirds were applied before the first irrigation. Phosphorous in the form of Calcium superphosphate (15.5 % P2O5) at a rate of 238 kg/ha and potassium in the form of potassium sulfate (48 % K2O) at a rate of 119 kg/ha were applied as one dose at field preparation.

A split-plot design was used where three irrigation treatments represented the main plots and two wheat cultivares in sub-plots with four replicates.

The experimental unit was 150 m^2 (12 × 12.5 m) consisted of 80 rows of 12.5 m length and spaced 15 cm apart with a border of 1.5 m between plots.

3. Growth, Yield and Some Yield Attributes

For determining yield, an area of 30 m^2 from the center of each plot was harvested to estimate grain and straw yields of two wheat cultivars; Sakha-93 and Gemmieza-9. The following crop parameters were measured:

1. Plant height at harvest (cm)
2. Grain weight per spike (g)
3. 1000-grain weight (g)
4. Number of spikes per m^2
5. Grain yield (ton/ha)
6. Straw yield (ton/ha)

4. Results and Conclusion

Growth, yield and some yield attributes: Statistical analysis revealed that different irrigation treatments had a significant effect on growth of wheat plant as expressed herein in plant height in the three growing seasons. The study also, indicated that decreasing number of irrigation events resulted in corresponding significant decrease in plant height in the three seasons. Such decrease may be attributed to the decrease in the activity of meristematic tissues responsible for elongation.

These results are in agreement with those obtained by Khater et al., (1997), Nahla et al., (2002), and Atta (2002). Data also, confirmed that Gemmieza-9 cultivar was significantly superior to Sakha-93 cultivar in plant height. The difference between the two studied cultivars could be attributed to their different genetic constitutions as well as their response to the prevailing environmental conditions.

Yield attributes of wheat crop

The data obtained revealed that deficit irrigation had significant effects on number of spikes per m^2, grains weight per spike, and 1000-grain weight in the three seasons. The highest of these characters were obtained from (5-irrigations) followed by (4-irrigations), however the lowest values were gained from treatment (3-irrigations).

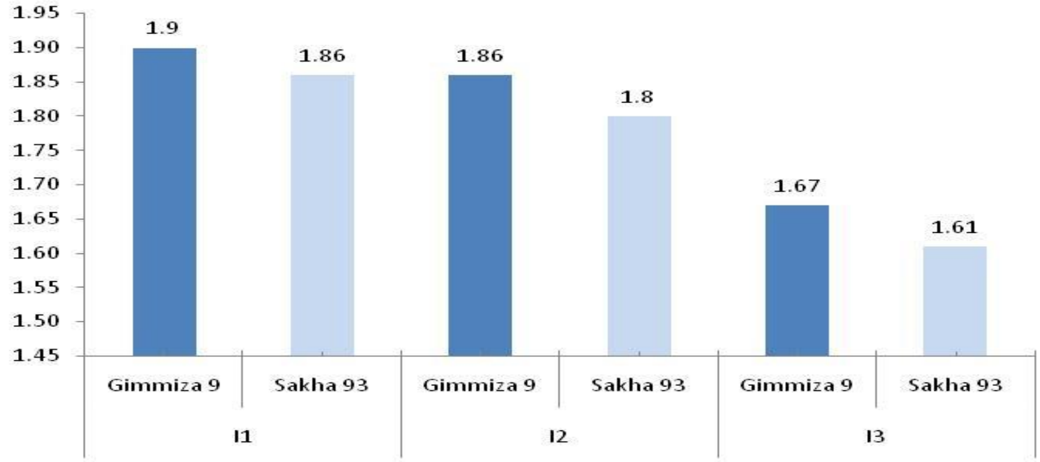
The results indicated that subjecting wheat plant to moisture stress during the reproductive phase led to significant reduction in yield components like spike grain weight and 1000- grain weight consequently reduction in grain yield.

The results agree with those obtained by El-Menoufi and Harb (1994); Khater et al (1997) and Nahla et al (2002). Concerning the differences among cultivares regarding the grains g/spike, No. of spikes/m^2 and 1000-grain weight reached the significant level.

5. Water Productivity (WP)

WP of two wheat cultivars as affected by irrigation treatments as an average in the three growing seasons as illustrated in Figure (7.c3.1). The values of WP ranged from 1.67to 1.90kg/m^3. The highest value of WP (1.9kg/m^3) was observed at treatment I_1 while the lowest one (1.67kgm^3) was observed at I_3. Such a result indicates the importance of giving proper amounts of water at the proper physiological stages of growth to maximize crop production per unit of water. These results may be attributed to the highly significant differences among grain yield as well as difference between the water consumptive uses.

Similar results were also reported by Abd El-Gawad et al., (1993) who found that WP for wheat was higher under dry soil moisture levels than wet conditions. Also, the same trend was observed by El-Refaie and Hamada (1994), Osman et al., (1996), Khater et al., (1997), Nahla et al., (2002) and Atta (2002). In respect of the studied cultivars, it is clear that Gemmieza-9 cultivar gave more WP value than Sakha-93 cultivar.



13. Fig. (7.c3.1) Water productivity as affected by number of irrigations for two wheat cultivars as an average of the three growing season

6. Conclusion

Options to reduce the gap between water supply and demand is a crucial when dealing with water scarcity coupled with rapid population growth and the potential negative impacts of climate change on agriculture production systems. This research attempted to overcome the problem of canals' ends in Delta whereas water supply is a serious problem. The aim of this investigation was to study the effect of deficit irrigations on water consumptive use, some water relations, yield and some yield attributes of wheat crop in order to set the management tool for managing water under water shortage conditions.

The results indicated that applying the optimum number of irrigations resulting optimum yield. The results showed that number of irrigations events could be decreased with slight, but insignificant decrease (7 and 10 %) in the grain and straw yields respectively. This means that applying four irrigations instead of five could safely save about 19 % of the annual commonly used water applied volume per hectare.

Therefore, it is concluded that, to maximize wheat yield of Gemmieza-9 and Sakha-93 cultivars, five-irrigations should be applied under East Delta conditions, while in case of low water supply, four irrigations is recommended and it is adequate as an alternate solution to mitigate with water shortage. In general Gemmieza-9 cultivar gave higher grain and straw yields than Sakha-93 cultivar. The seasonal water consumptive use values were 33.6 and 31.9 cm for Gemmieza-

9 and Sakha-93 cultivars respectively, it means that Gemmieza-9 cultivar utilized water more efficiently than Sakha-93 cultivar. These results may be due to the cultivars genetically effects. So it is recommended to be cultivated under such conditions.

Wheat plants uptake about 74 and 26 % of its water needs from the upper and the second layer, respectively for treatment I1 while treatment I3 resulted in increasing the water uptake by roots from the second layer (29 %). Crop coefficient values were calculated according to reference evapotranspiration (ETo) and the daily actual evapotranspiration (ETc) derived from the optimum irrigations treatment for two wheat cultivars which produced the highest wheat grain yield. It is recommended that to use the updated empirical value of the crop coefficient, Kc, to calculate consumptive water use of Gemmieza-9 and Sakha-93 wheat cultivars at East Delta Region.

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Case Study 4: Mechanized Raised-bed planting in Egypt: An Affordable Technology to Rationalize Water use and Enhance Water Productivity

*By : Dr. Atef Swelam**

1. Background

The concept of raised planting is nothing new for Egypt Delta farmers; it has been utilized from long time ago. The ancient Egyptians simply were making furrows. That is the raised-bed planting at its simplest way.

Raised-bed planting (fig. 7.4A1) has a better performance as there is less need to apply water to all land, which leads to a decrease in percolation losses. Planting wheat on the ridges, insures good aeration of the roots, better use of solar radiation, efficient use of fertilizers and easier weed control and other agricultural practices (fig. 7.4A.1).

Nowadays, farming system is an intensively, based agriculture, farmers, are widely using raised-bed planting for several sequenced seasons utilizing the same furrows and farm layout of the previous crops to save time and to wave land preparation costs for the next crops. This is a cost-effective way of conservation farming.

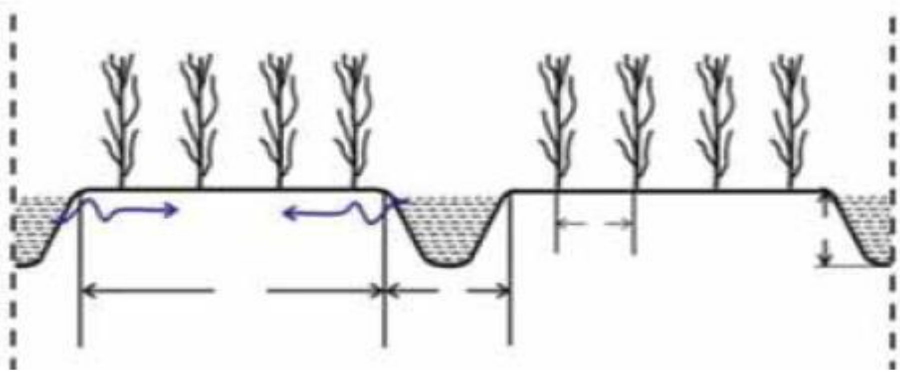

Fig. (7.4A.1) Raised-bed planting

2. Mechanized raised-bed system(MRB): small farms mechanization in Egypt is a difficult process due to economic concern when purchasing and operating farm machinery. Small farm size requires simple machines to do hard work in a short time in very fragmented lands. The selection of appropriate machines, is a critical factor for sustainable use under areas conditions.

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* Atef Swelam (2016): Senior officer ICARDA, Science impacts issue ICARDA issue **www.icarda.org** /publications. Resources

The key factors associated with machine selection for the Nile Delta lands are:

- Machine size suitable for fragmented land.
- Cost effective machine
- Machine weight suitable for soil to avoid compaction

2.1 Description

Through irrigated benchmark project in Egypt ICARDA has developed an multi crop raised bed machine. Dr. Atef Swelam, ICARD'S water management scientist in collaboration with other scientists from NARC and NWRC, developed a multi-purposes raised bed machine that can be used for sowing different crops in the old lands of the Nile Delta.

Photo: (7.4A.1)

The prototype has been developed on the base of some machines from India and other's adapted to the specific soil and water conditions in the Delta Area (tested in Sharkia Governorate)

A new bed forming and sowing by this machine has been provided; (Photo 7.4A.1) it is smaller appropriate for available regular tractors and capable of forming two 130 cm bed or four 65cm beds. With this improved machinery it should be possible to practice genuine no-tell farming with good storage efficiency at the active root zone and further improve all irrigation efficiencies and crop productivity. These smaller wide and narrows beds-were tested for maize, wheat, sugar beet in other areas for better yield and improved water use efficiency.

The developed raised-bed machine was designed to assure that all plots are planted with no skips or doubles planting.

This multi-crop machine can be used for fine seeds like bersem as well as for large seeds like fababean.

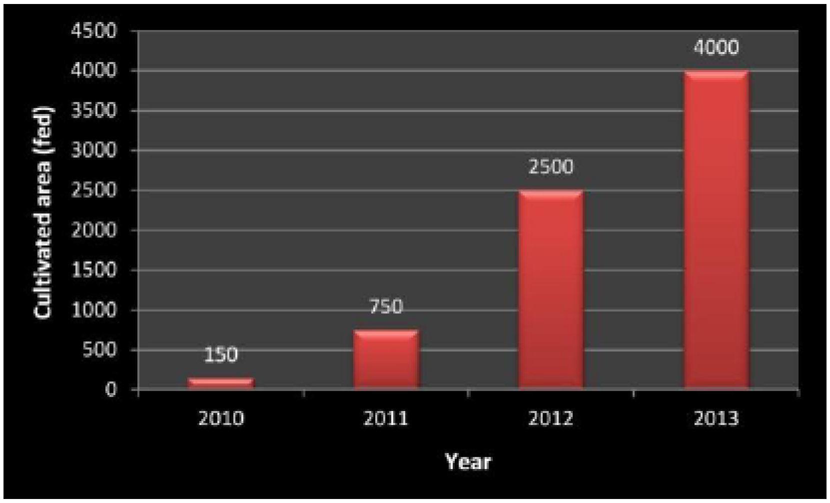
Photo: (7.4A.2) implementation process of the machine

3- Impact of the Raised-Bed Machine Innovation

3.1 Economic impact

Based on the actual farming expenditures for wheat, the economic analysis for MRB and the conventional method showed that applying MRB achieved high economic benefits, due to “yield increase and cost reduction”. The number of furrows was half that of conventional fields, this means less water applied to the field hence the pumping cost was reduced by 20-30%; labor costs for preparing land, irrigation and weeds control also dropped by 30% fertilized cost was dropped by 25%.

The net return of crop yield (ton/ha) was 25% higher than that from conventional furrow irrigation (fig 7.4A.2)



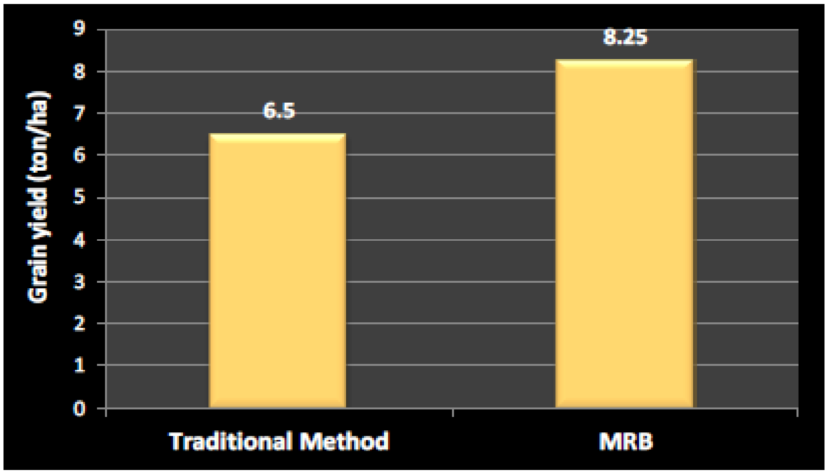


Fig. (7.4A.2) shows cultivated area for years and grain yield (ton/ha)

3.2 Social impact

The new machine was manufactured locally and it can make a quantum leap in local investment for fresh graduates, since the raised-bed planting system has a great potential in Egypt lands.

3.3 Irrigation water use

As an average mechanized raised-bed achieved an average 22% irrigation water saving. This is shown clearly in fig (7.4A.3) indicating the water productivity increase in the MRB than in the traditional method. One of the benefits out for using mechanized raised-bed planting was better drain the excess water from active root zone of the crop. This was to avoid water logging especially at not flattened beds which improved the local distribution uniformity in the field.

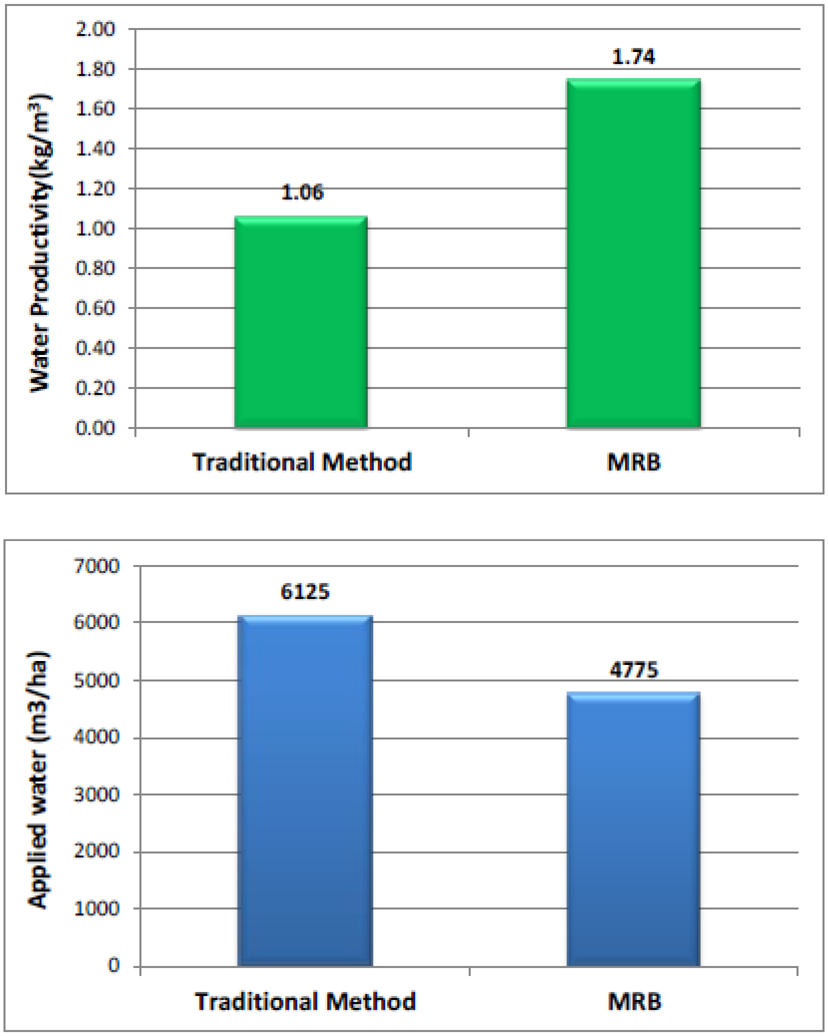


Fig. (7.4A.3)

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Case Study 5: Save Irrigation Water using the Innovative Machine of Soil and Water Management for Rice Crop Cultivation (SWMR)

*By: M. El-Hagary**

1. Introduction

Irrigated rice receives an estimated 34−43% of the total world's irrigation water, or about 24−30% of the entire world's developed fresh water resources.

There are about 150 million hectares of rice land, which provide around 550–600 million tons of rough rice annually (Maclean et al 2002). Rice crop is considered one of the most important foods and export crop in Egypt. In the last ten years, the annual cultivated area increased from 1.08 to 1.56 million feddans (0.65 million hectares), and the grain yield increased from 3.14 to 5.80 million tons. The average grain productivity was 3.42 tons/fed. (Ghonimey and Rostom, 2002). There's the modified method of cultivation rice in the bottom and strips (Yousri Ibrahim Atta, 2005), it also saves a lot of water, but reduces the used land area according to the description of a new method (Top of furrow 45cm. And 35 cm of the bottom). The rice intensity is two plants per 80 cm crosswise, while in this innovative method there are four plants in 80 cm crosswise. It's meant that the double yield under the new technique that will be explained. The objective of this work is how to save water applying a new technique for rice cultivation.

2. The innovation technique description

Soil and Water Management Machine for Rice Cultivation (SWMR) will save water, nutrients, time, efforts, applied energy, and operating costs and of course the ratio of weeds growing will be reduced. The new technique needs an innovative machine to manage soil for 20 cm depth, is designed and manufactured to be suitable to the hard environment work conditions like, heavy and compacted soil. Fig (7.5B.1)

SWMR Machine is manufactured of a cylinder rule having many of circular protrusions around the basic cylinder rule to roll after subsoil chisel of depth 25 cm under the soil surface, behind the tractor on soil and printed the designed formed of cross section of trenches which faces the transplanted rice rows, all of rule machine will be moving on axe by suitable ball bearings and connected to frame having a three kink points to tractor. Section of trench width (20 cm) of the furrow edge space (reformation of soil surface to furrows having the (V) shape, beside the modification of transplatier float by installing the modified wheels to be suitable to the furrow shape, Fig. 7.5B.1, 7.5B.2, 7.5B.3, 7.5B.4 and 7.5B.5.

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*Dr. Mohamed E. El-Hagarey (2016): Researcher, Irrigation and Drainage Unit, desert research center, of the MALR, Cairo, Egypt.

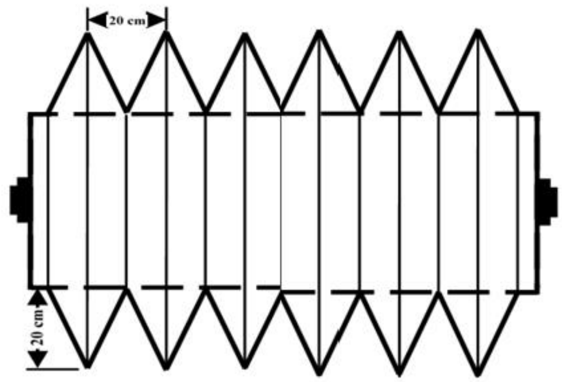

Fig. (7.5B.1) the side view of Zigzag shape which reformation the soil surface.

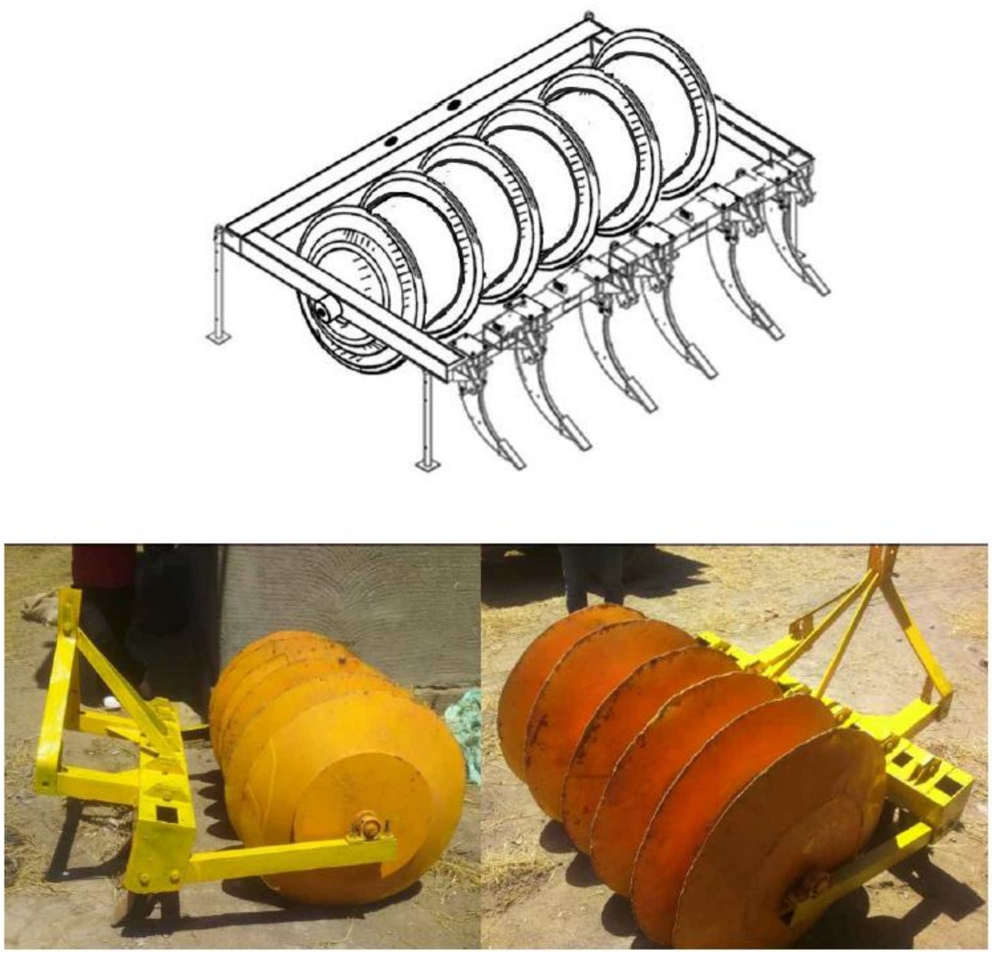

Fig .(7.5B.2) the innovative machine of soil and water management (SWMR)

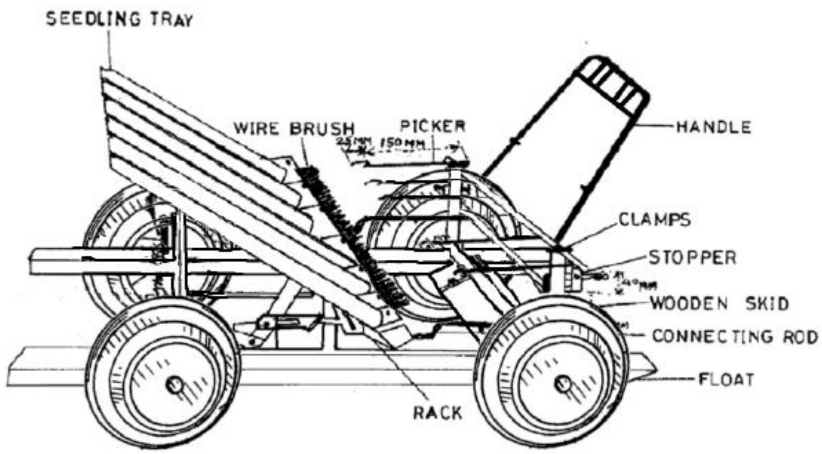

Fig. (7.5B.3) the Modified rice transplanted of the new innovative technique of rice cultivation

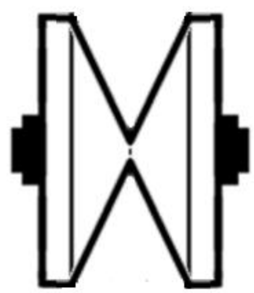

Fig. (7.5B.4) Modified wheel of modified transplanted lakes the cross soil furrow shape

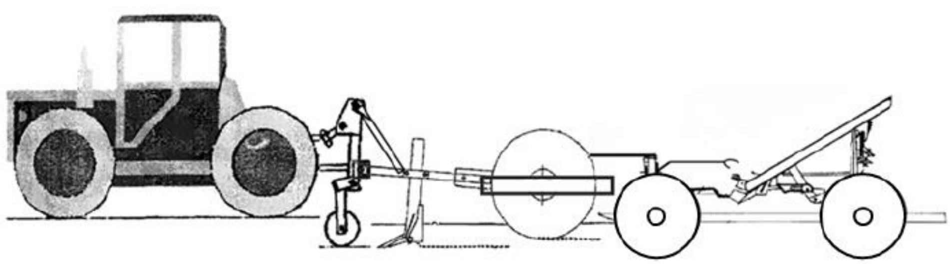

Fig. (7.5B.5) the innovative cultivation system machine (tractor, SWMR) and modified transplanted

3. How the innovation save the water

The new technique of rice cultivation depends on translating rice in the bottom of a long trench have cross section V shape, like that the rice didn't have any water stress and the volume of water becomes about 50% of the irrigated water under the traditional method.

Rice was cultivated under two methods traditional method (WT) and modified innovative method (Wm) in furrow bottoms. The cross section of furrows such as a zigzag shape using a soil management and soil bed preparation (soil surface shape) using innovative machine to soil bed preparation to harvest irrigation water. Without any reducing of rice intensification, and rice is transplanted at 20 × 20 cm in both of two cultivation methods. The amounts of applied irrigation water were measured and calculated.

Irrigation requirements

Irrigation water requirements for rice will be calculated according to the local climate station data at Kafr El-Sheikh Governate, the Central Laboratory for Agricultural Climate (C.L.A.C.), Ministry of Agriculture and Land Reclamation.

Measurements and calculations

Irrigation water saving percentage

Water saving = (If – In) / If x 100

Where: If=Water use for control treatment (m3/ha), and In=Water use of various treatments (m^3/ha).

Irrigation water use efficiency

(IWUE) (kg/m^3). Irrigation water use efficiency calculated according to Viets (1962).

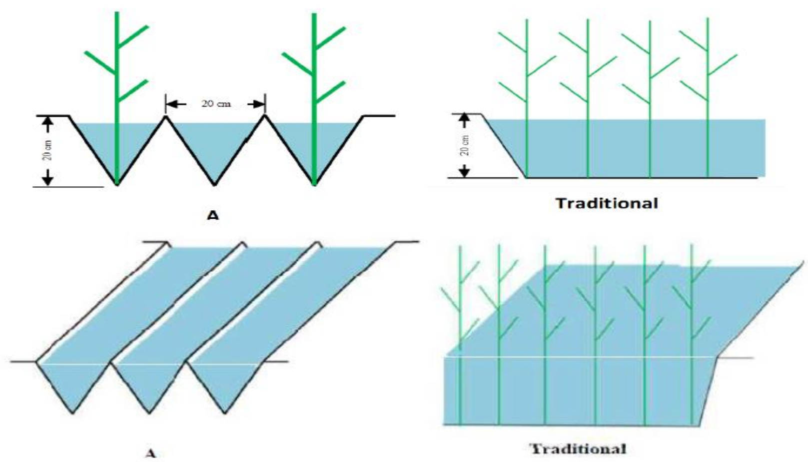

Fig. (7.5B.6) cross section (water flow area) of traditional and modified rice furrow irrigation

4. Results and conclusion

The investigation results show that, the amounts of applied irrigation water are 13104 and 6897 m^3/ha for the traditional and modified method of rice cultivation respectively, and then the Irrigation water saving percentage, it's meant the applied water of modified is lower than the traditional method by 47 %. The rice crop yield of one hectare is 8580 and 8978.4, kg/ha. for WT and WM, respectively. While the irrigation water use efficiency is 0.65 and 1.3 kg/m^3 for WT and WM, respectively, Figs. (7.5B7, 7.5B8, 7.5B.9 and 7.5B.10).

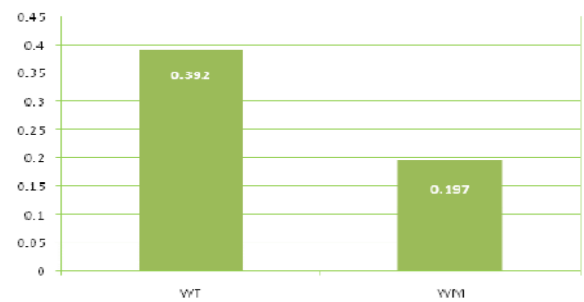

Fig. (7.5B.7) the amounts of applied irrigation) water (m^3/ha) Fig. (7.5B.8) the rice crop yield (kg/ha)

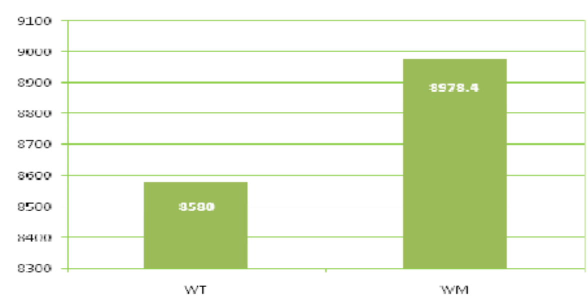

Fig. (7.5B.9) irrigation water use efficiency (kg/m^3) Fig. (7.5B.10) irrigation cost of production unit (EGP/kg)

It's clear the positive influence of a modified method of rice cultivation on the parameters of rice crop production and crop yield per hectare.

Also the saving of irrigation water in which harvest both of water and nutrients around the rice seedlings in the v shape of furrow irrigation, which include the rice plants and reduce the water losses by evaporation and runoff beside, reduce the environmental hazards than the traditional method which present a full surface of irrigation water Hence, present a perfect environment for mosquito and weed control.

Photo:11. The rice under the SWMR method and traditional methods

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Chapter 8

Integrated Approaches in Agricultural Drainage

Chapter 8
INTEGRATED APPROACHES IN AGRICULTURAL DRAINAGE

8.1 Introduction

Water resources management is a complex process that requires a multi-disciplinary approach in order to take all its facets into consideration. This integrated approach combines different aspects under one system that manages demand, supply, quality of water resources and well-designed drainage system, a necessary component of the overall water management system. Good water management in the broadest sense is critical for the global food production. A drainage system enhances agricultural production and leads to reduction of negative environmental impacts. Drainage systems are applied in 25% of the world agricultural lands. In Egypt it is already applied within 90% for all agricultural lands. Drainage systems are generally, one of the most determining factors in terms of water table control and impacts on the groundwater regime (soil moisture conditions) for agriculture. The management of existing drainage systems, should, therefore, be adopted accordingly, and remodeling of drainage infrastructures may be required. Being such a determining factor for the water regime existing and future drainage systems should be re-designed as “controlled drainage systems”. Which can serve as “effective tools to establish and maintain target ground and surface water regimes and allow for active intervention in integrated water management.

The government has taken several initiatives towards applying this approach and all the principles of (IWRM), which drainage is among these principles.

8.2 Controlled Drainage for Integrated Water Management and Irrigation Water Saving.

Controlled drainage

Is an essential component of integrated water resources management (IWRM) and water demand management (WDM). Controlled drainage plays an important role to save water and nutrients and to improve and optimize downstream water availability and quality.

Case (1) MODIFIED DRAINAGE SYSTEMS

Egypt, introduced modified drainage system in 1995 for rice areas in the Nile Delta as controlled drainage as shown in the following table (8.1). Controlled drainage is not only important to reduce water use during the rice-growing season, but will become an essential .

Table (8.1) from modified drainage to controlled drainage in Egypt

1977-1979	Experiments with water management in rice fields
1980-1988	Testing of the modified drainage concept in experimental fields and pilot areas Nashart, Roda and Mashtul
1992	Crop liberalization
Since 1992	Encouraging of farmers involvement in on-farm water management
1996	Controlled drainage study using collector user groups
1997	Controlled drainage study using water user associations
1998	Controlled drainage study using key-persons (influential people in the village)
October 1998	Land tenure liberalization
April 1999	Workshop was held to present the results of controlled drainage
2000	Multi-disciplinary team to apply the controlled drainage on a large scale
2001	Final report DRI and DRP2 with guideline for controlled drainage (DRP/DRI2001)

The principle of the system is shown in Fig.(8.1) by providing subsurface collectors and connecting these via manholes, and fitting the outlets in the manhole with simple locally produced gates, it is possible to drain the field with a non-rice crop and stopping discharge from the field with rice. The method requires more drainpipes, and it was calculated that the construction costs of a system with additional sub-collectors, manholes etc: would cost 16-25% more per hectare. Although this is a substantial increase, it actually only increased the cost component of the farmers seasonal budget by 5-10%. No detailed calculations of cost recovery of a system constructed completely as a controlled drainage system have been made yet, but the costs of installing gates in existing systems was recovered in one to two seasons. For primarily maintenance reasons, and reducing risk of area affected when a collector fails, the present Egyptian subsurface drainage systems has sub-collectors in about 18% of the area which can be used for the system described before. Except for the experimental areas of DRI none are equipped with gates. The typical area served by sub-collectors is between 10 and 40 feddans (approx..4-17 ha).

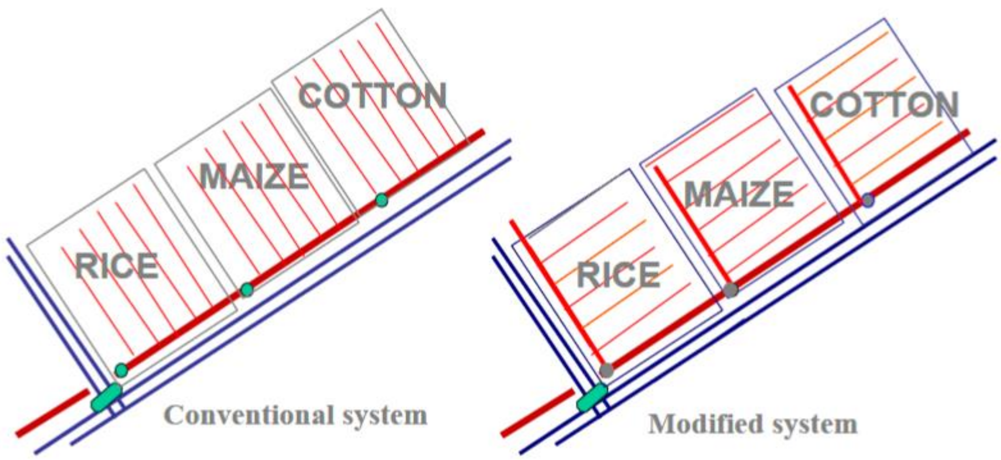

Fig .(8.1) comparison of conventional and modified drainage system design

- **Detailed layout and design of modified drainage systems**

With the current conventional layout see fig. (8.2) of the drainage system and the prevailing cropping pattern, the rice fields usually share the same drain, with other crops fig. (8.1) in a random pattern that changes with the crop rotation.

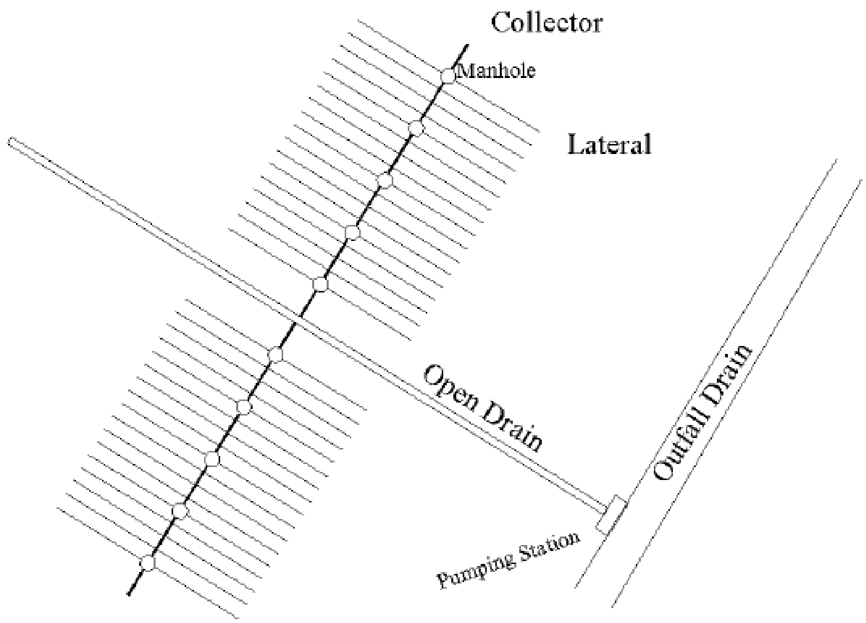

Fig .(8.2) conventional layout of the drainage system

The presence of buried drains causes continuous and unnecessary high drainage rates from rice fields. Farmers find a way to block drains during the rice season or keep replenishing the ponded fields putting a plug in a pipe outlet at a manhole usually stops drainage not only from the rice fields but also from all other fields upstream of the blocked section. This situation may cause damage or series yield loss of the other crops which include cotton.

The modified system (fig 8.3) basically consists of a main collector drain and a sub collectors. Each subcollector serves a unit area which is under the same crop during each cropping season of a crop rotation. The sub collectors join the main collector at manholes where a simple closing devices fig. (8.4) can be fixed to their outlets. Different types of closing devices as shown in fig. (8.5) are tested too. When the area served by a subcollector is cultivated for rice, the outlet can be easily operated according to the required water management in the rice fields. The rest of the subcollectors serving other crops will continue to have their outlets open during the full-growing season. The main collector drains will strictly act as a transport conduit to which no lateral drains are connected and will be flowing freely at all times.

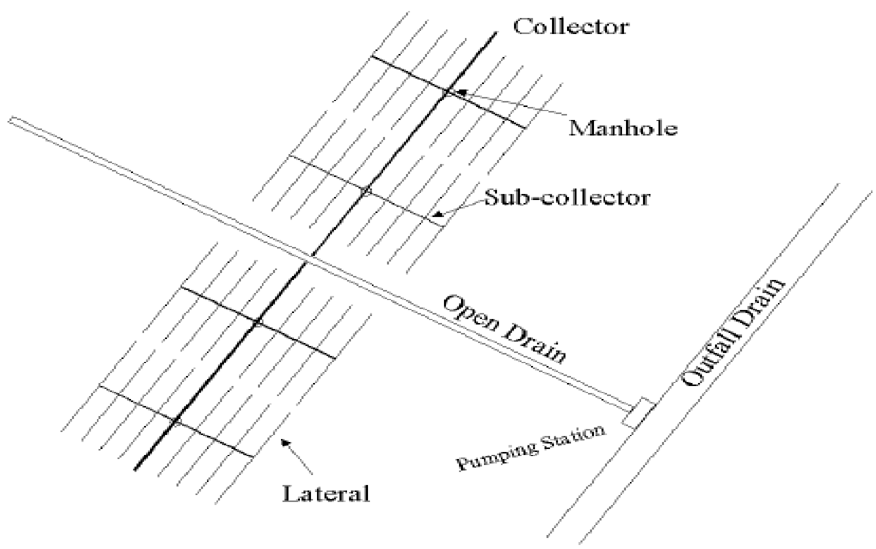

Fig. 8.3 the modified drainage system layout

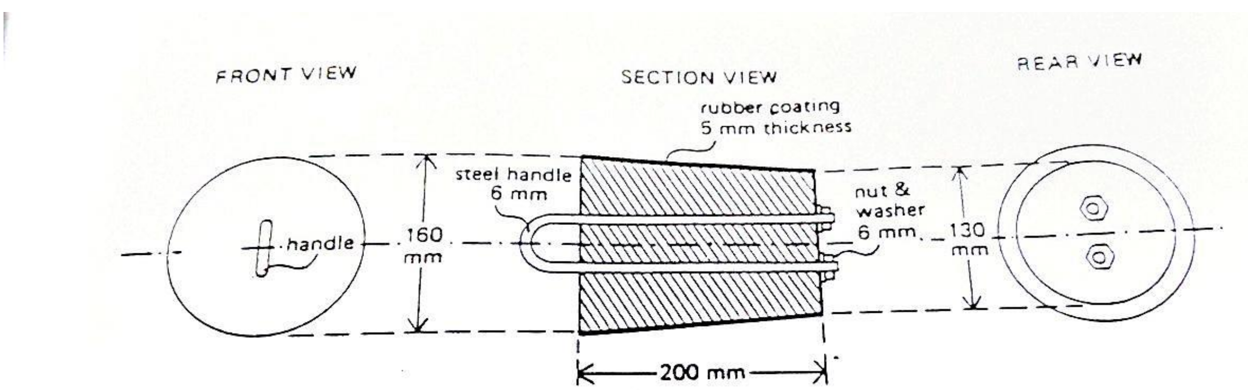

Fig. (8.4) simple wooden plug

The first pilot area designed according to the modified layout concept was constructed at the Bahr Saft area within the catchment area of the El-Mahmoudiya Main Drain. Since its completion in 1982, it was subject to monitoring and evaluation. Detailed study was carried out on the effects of soil salinity and crop yield in comparison with similar areas with conventional drainage systems **(DRI),** 1984a, 1985a, 1987b). Water and salt balance studies were also carried out at experimental fields (DRI, 1986a) with controlled water management systems. The study continued for five years. It included also an evaluation of the availability of design data on the crop pattern, the cost of construction, and operational requirements including the type and shape of the closing device (DRI,1986b). A second pilot area of the same size (4000 fed.) was designed and implemented at Kafr El-Sheikh area.

Among the most important features of this study were the potential saving in irrigation water as a result of implementing drainage systems with a modified layout instead of the conventional one. The savings system from the fact that they operate without allowing excessive water losses during the rice season. The water balance study revealed that the area with a modified layout required approximately 35% less irrigation water compared to the area with a conventional layout as shown in table (8.2). The modified drainage system will reduce the drainage rates during the summer season when rice is cultivated. This can be translated into less need for pumping and fewer overflowing main drains during the season. On the other hand, there will be no need for the unauthorized blocking of the system to stop that unnecessarily high drainage rate of the rice fields. Consequently, no damage will occur to the other crops sharing the same collector drain with the rice. Meanwhile, the maintenance problem will also be reduced due to the absence of unauthorized blocking.

Table (8.2) irrigation water used for rice growing for modified and conventional drainage systems.

Type of drainage system	Irrigation water in m^3/season		
	Sharkia (East Delta)	Kafr El-Sheikh (Central Delta)	Beheira (West Delta)
Conventional	6 709	5 683	9 525
Modified	3 698	3 017	6 501

The water management study (DRI, 1986a)* in the rice fields at different geographical areas with different soil conditions proved that there is

* see Amer, M.H. and N.A.de Ridder (1989)

no accumulation of salts in the rice areas as a result of closing the drain outlets. The natural drainage and discharge after opening the closing devices at the end of the rice season were enough to leach out the salt. There were no significant differences in rice yield (Abdel-Dayem et al, 1987a) on other crops (DRI, 1987e) in the areas with modified systems when compared with areas provided with conventional systems, as shown in table (8.3).

Fig. (8.5) Different types of closing devices for subcollector in rice growing areas.

Table (8.3) yield of summer crops in areas with conventional and modified drainage systems

Area	Year	Crop yield in tons/fed*.					
		Conventional			Modified		
		Rice	Cotton	Maize	Rice	Cotton	Maize
Mahmoudiya	1983	2.1	1.1	1.4	2.6	1.3	1.9
Mahmoudiya	1984	2.5	1.2	1.6	2.6	1.3	2.8
Mahmoudiya	1985	3.0	1.4	2.1	2.3	1.5	2.2
Mashtul	1986	2.1			2.1		
Zankalon	1985	2.2			1.8		
King Osman	1985	2.1			2.2		
Sakha	1985	3.0			3.4		
Roda/Nashart	1986	2.5			1.6		
Roda/Nashart	1988	2.7	1.1	2.3	2.8	1.0	1.9
Overall average		2.5	1.2	1.9	2.4	1.3	2.2

Fed=4200.54m^2

The design drainage rate of the covered drainage systems in the rice growing areas can be the same as in the areas without rice in the crop rotation. As a result, the cross-sectional areas of the pipes will be less than those currently designed for conventional systems in rice areas. The increase in the length of the pipes due to using additional subcollectors is compensated by the reduction in the pipe size (DRI, 1986b). Thus there is no increase much in the capital cost of the drainage systems as a result of adopting a modified layout.

The preparation and production of crop consolidation maps to prepare a modified drainage system are needed for pre-design activities while they are unnecessary for the design of a conventional layout. Moreover, the modified drainage system requires special arrangements for the operation and maintenance of the closing devices.

Case study (2A) MODIFIED DRAINAGE SYSTEMS (APPLICATION FOR LARGER RICE AREAS)

*By: Dr. M.B Abdel Ghani et. al.**

1. Background

The subsurface drainage systems installed in Egypt are generally of the composite type, which means that they consist of lateral and collector drains (Figure 8.2). The laterals are on average 200 m long. The collectors, which transport the water to open drains, vary in their length from a few hundred meters to more than two kilometers depending on the topography and the layout of the main irrigation and drainage systems.

In rice areas provided with subsurface drainage some farmers were obliged to close the drain outlets using straw and need to keep standing surface water in the field as long as possible. These methods of field water management from the farmers point of view caused many problems on system maintenance. Therefore DRI and EPADP started to study and implement modified drainage systems in rice areas. Drainage of rice should be based on the following principles (Abdel Dayem and Ritzema, 1987):

• To operate the covered drains in the rice fields independently from the rest of the drainage system. This can be achieved by using a subcollector drain for each crop area;
• To reduce the outflow from a field cultivated with rice a closing device should be installed in the downstream part of the subcollector. If other crops than rice are cultivated the closing device should be left open, enabling unrestricted outflow conditions;

• The design criteria for pipe drain capacity of a modified layout can be the same as those applied for non-rice areas. In the conventional design, a drainage duty of 4 mm/day is applied for the calculation of drain capacities for areas with rice in the crop rotation versus *2* mm/day for non-rice areas. With the modified layout this increase in capacity is not necessary. Even on occasions when rapid drainage is required, e.g. for renewal of the standing water in a field or at the end of the rice season, which can be achieved by accepting temporary over pressure for short periods.

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The major objective was to minimize the drainage flow from the rice field (controlled drainage) and at the same time to allow free drainage flow from the other crop fields (conventional drainage). A modified drainage system layout was developed (Figure 8.6B). An investigation programme was conducted from 1977 until 1979, while, during the period 1980-1988, the concept of the modified drainage system was developed and tested both in experimental fields and in pilot areas. A total of 5400 ha was constructed according the modified drainage system principle. By the mid 90's there were two developments in Egypt which affected the implementation of the modified drainage systems:

1. The abandonment of mandatory crop consolidation in 1992, leaving, the farmers free to choose the crops they like. Hence, the block system of land use could not be imposed anymore;

2. The government plans to involve farmers in the on-farm water management and make them more responsible for operation and maintenance of the irrigation and drainage systems.

The aspect of free non-consolidated cropping patterns decreases the chances for implementing modified drainage systems. However at the same time, the move to stimulate farmer's participation in on-farm water management may help to introduce these systems. The Egyptian Public Authority for Drainage Projects (EPADP) is moving towards farmer's participation in the operation and maintenance of the subsurface drains. This is one of the requirements for successfully operating the modified system. DRI therefore, followed up on a suggestion of the Advisory Panel on Land Drainage, to investigate the possibility of applying the modified drainage system design and principle of operation under the new conditions.

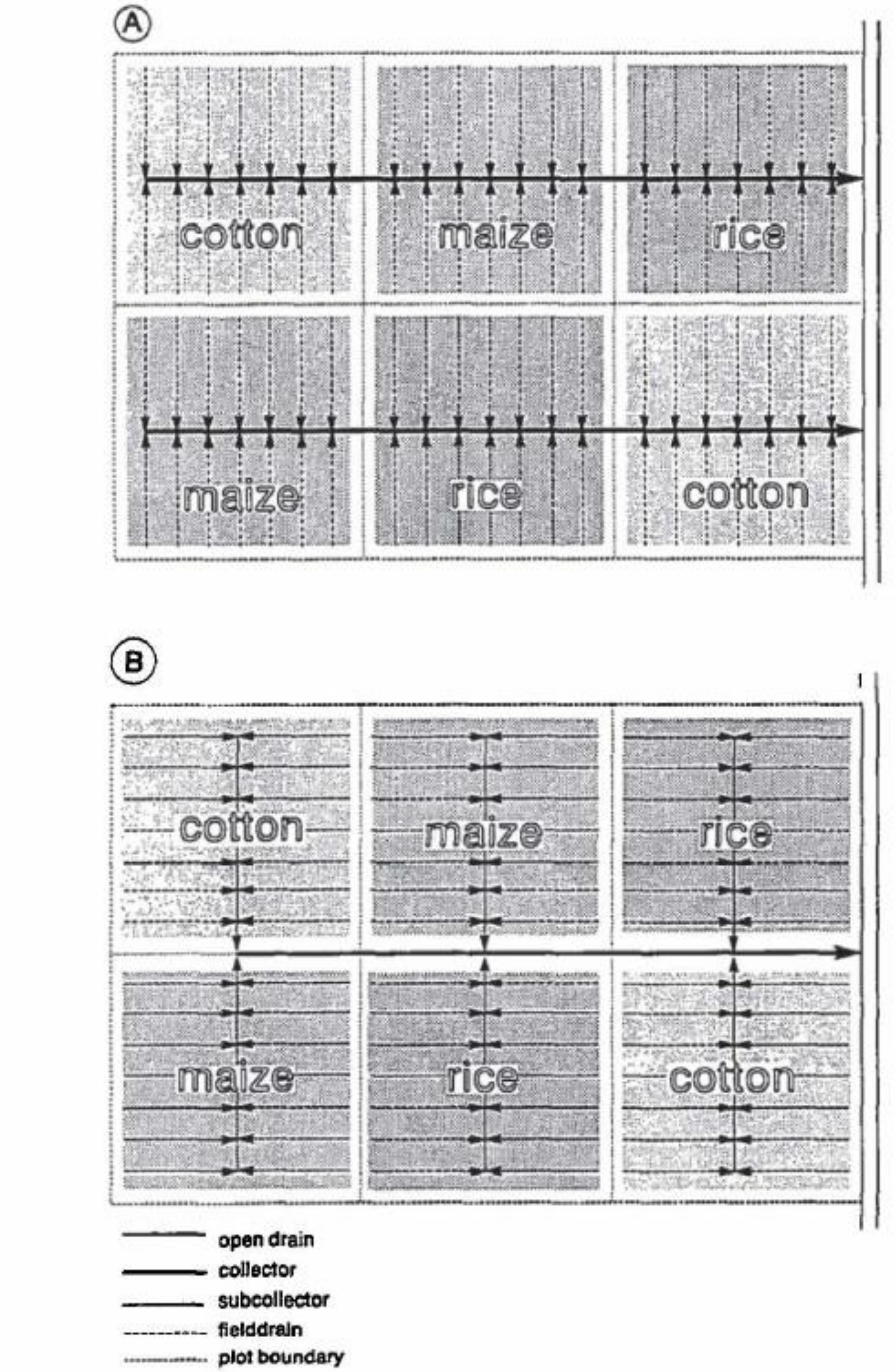

Fig. (8.6) Layout of conventional and modified drainage systems (Cavelaars et *al., 1994).A: Conventional layout, not adapted* to *the cropping units B: Modified layout, adapted to the cropping units.*

2. Water Management Observations

From 1977-1979 DRI carried out a field study on the water management in rice fields during three successive summer seasons (1977, 1978 and 1979) in the North West of the Delta near Damanhour (Figure 8.7). It was found that although yields remained the same or slightly increased with subsurface drainage, there was a continuous loss of irrigation water standing in the rice fields through percolation to the subsurface drains. The amount of water removed by drains from the rice fields was estimated at 5-10 mm/day. In order to compensate these continuous subsurface drainage discharges, an increase in irrigation water is required. In areas with a shortage of irrigation water supply, especially during and for some time after the nursery bed stage, the lack of water may cause an adverse effect on the crop. A temporary closure of the drainage system was therefore recommended.

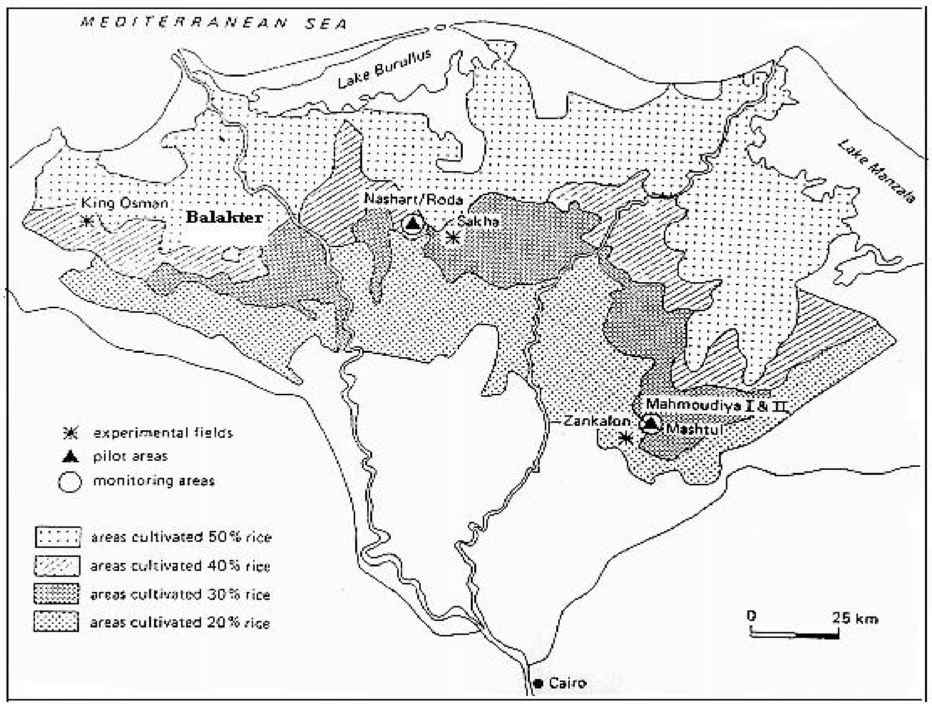

Fig.(8.7) Location of the study areas

3. Testing of Modified Drainage System

The modified layout of the drainage system was introduced in 1980 at the Mahmoudiya-1 drainage project in the Bahr Saft area in the Eastern Nile Delta (Amer and De Ridder, 1989). It consists of covered main collector drains with subcollector branches. Each subcollector serves an area coinciding with a "one crop block" of the crop consolidation system (Figure 8.6 B). The junction of the sub collector to the main collector consists of a manhole with a suitable device for regulating the subcollector outflow. In this way, there will not be a need for unauthorized blocking of the system and regulation will be carried out without any conflict for the drainage requirements of the various crops. The most important feature of the design criteria for a modified drainage system in areas with rice in the crop rotation, is the design drainage rate which is the same as for non-rice crops. This implies a reduction in the pipe size as compared to the current design norms and consequently a saving in construction costs. In addition the introduction of the modified system indirectly helps in saving precious fresh irrigation water. After comparing the results of the study it was concluded that the results obtained in the experimental fields (King Osman, Sakha, Zankalon) in 1984 are in agreement with those of the detailed studies carried out in farmers fields in respectively Mahmoudiya, Mashtul 1986and Nashart and Roda 1986.

- **The conclusions are summarized as follows :**

The introduction of a modified drainage layout in the rice growing areas in the Nile Delta will:

- Save between one and three billion cubic meter of irrigation water which would otherwise be lost through the subsurface drainage system in a total area of 1 million feddans in the Nile Delta (being the difference in drainage rate between the conventional and modified system 1-3 mm/day over a growing season of 100 days);
- Save the drainage system from unauthorized and improper interference of farmers to stop irrigation water losses from rice fields through the subsurface drainage system;
- Save other crops than rice from the damaging effects of the improperly blocked conventional collector drains.
- These benefits are obtained without causing any negative effects on either the soil salinity levels in the blocked sub collectors of the modified system or on the yield of cotton, maize or rice.

Since the detailed research by DRI, seemingly little was done about the modified drainage system. However, EPADP experienced problems with the O&M of long collectors in, amongst others, rice areas. When farmers blocked long collectors large areas were affected.

Hence EPADP adjusted their designs to short collectors, or long ones, but with subcollectors. If farmers then would block the collector only a small part would be affected. EPADP did not install gates at the end of the subcollectors but left the decision on how to close/block to the farmers. EPADP did not call the system 'Modified Drainage', but in fact they are. The main objections to the gates were the costs and the more difficult maintenance and operation of systems with gates.

Therefore since 1988 very little has been done with the modified drainage system principle.

Reasons to look more into the application of the modified drainage system are:

- the increased interest in creating more water for new irrigation areas and the increased awareness of the limited supplies of the Nile River;
- the world wide attention given to controlled drainage, not only from water savings point of view, but also to control the environmental impact of drainage systems;
- the attention to involving farmers in O&M of irrigation and drainage systems in Egypt, which is actively taken up by EPADP for management of its drainage systems.

The objective this time is to first interest the farmers in the idea, and then see if further changes are necessary in the subcollector design as presently used by EPAPD. At the same time the legal option to formalize the organization of farmers needs to be looked.

4. Controlled Drainage With Collector User Groups (CUG)

DRI approached the farmers in the area of interest indirectly: they firstly identified which organization had the trust of the farmers. It was decided that the Cooperatives" of the Ministry of Agriculture were the best focal point for DRI's intentions. The Cooperatives provide farmers on a day to day basis with advice, provide fertilizer, seeds and assists with resolving any problem that might occur in the field. Over time they have built up a good reputation amongst the farmers. The staff of EPADP's Maintenance Centers in the area (which are responsible for the O&M of the drainage system) were also involved right from the start, but as their interactions with the farmers are less intensive, they were not selected as the main go-between DRI and the farmers. DRI then arranged a meeting at EPADP's Damanhour office, the Cooperative staff, the EPADP Maintenance Centre staff, and EPADP's Regional Headquarters staff, and introduced the plans as well as arranged which areas to perform the tests. The Cooperatives then talked with the farmers and introduced DRI staff. Video tapes were made of these meetings. During subsequent meetings with the farmers (always under guidance of the Cooperative and at the Cooperatives quarters in the area or in the field) a memorandum of understanding was drafted which primarily assured cooperation between farmers and DRI to install the necessary equipment for the experiment.

For each of the subcollectors selected the farmers elected a leader of the CU Group with concurrence of the Cooperative. All parties involved the leader of the farmers and the representatives of the Cooperative, DRI and EPAPD's Maintenance Centre signed the MOU.

The leaders became the direct contact point for the DRI staff in the field, and assisted with installing the gates, arranged field observers, performed measurements, etc.

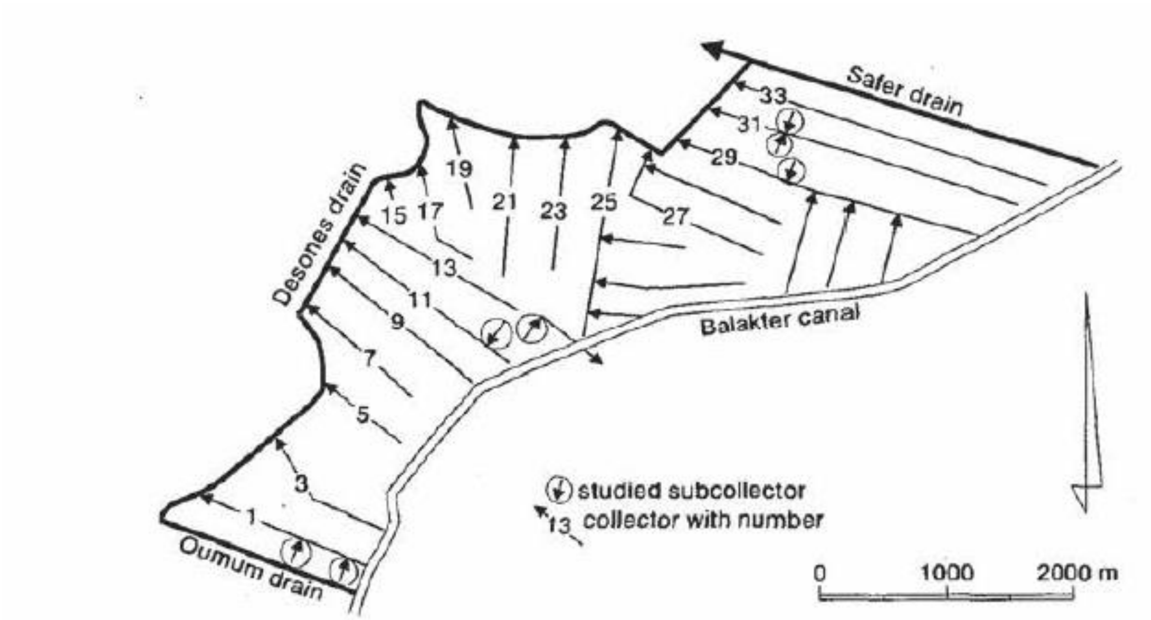

Fig. (8.8) Location of collectors selected for the study

Finally seven collectors were selected; five subcollectors along which farmers agreed to consolidate rice, and two conventional collectors in areas close to the subcollectors where rice consolidation was not practiced. Table (8.4) gives some of the characteristics of each of the (sub) collector areas. The study was conducted at Balaktar area (Figure 8.8) which is situated in the Western Delta, 20 km east of Damanhour in Beharia Governorate (Figure 8.7).

Special closing gates designed by DRI (DRI, 1987) were supplied to the five subcollector CU Groups and DRI assisted with the installation of the gates. Operation and maintenance of the gates were fully the responsibility of the CU Groups. The gates were left open till rice plants were transplanted from the nursery beds to the main fields; then they were closed.

In order to monitor what was going on in the fields the following observations were made:

- The groundwater table depth under the rice fields;
- The groundwater level in the rice fields from installed staff gauge to check the amount of water applied;
- The discharge of a number of diesel pumps were determined;
- The rice yield of 1994 was determined through interviews with farmers;
- The 1996 rice yield was determined from crop sampling;
- The costs of fuel and rental of irrigation pumps were determined;
- Soil samples were taken before and after the season to determine soil salinity levels;
- Periodic meetings were held with the farmers · to solve any problem during the study period.

4.1 Results first season (1996)

The Collector User Groups (CUG) which are formed for the first time for field drainage do not have a formal structure, but are a voluntary group of farmers. After one month since the starting of the study, the farmers of modified collectors noticed that the closing of the collectors prevent drainage and reduced the frequency of irrigation applications to the rice fields. Consequently, this helps in saving money for the farmers. For the modified drainage system, the response of accepting the idea of farmer participation in CUG are quicker in the collectors with a higher percentage of educated farmers. Table (8.4) shows the modified collectors under study and the educational level of the farmers. It is observed that collector no.1 has the highest percentage of educated farmers followed by collector's no. 12 and 11 respectively. The results obtained from these collectors showed that these collectors do not need more time to accept the CUG. During the study period religious people in mosques and churches were informed about the study by DRI engineers and consequently they invited the farmers to participate in this study. Many farmers have accepted the idea and meet with DRI staff to apply the study for the next year.

Table (8.4) Characteristics of collectors with collector user groups

Collector number	type	area feddan	number of rice fields out of total fields	number of farmers	farmers with schooling %	farmers with no schooling %
Agreed to rice crop consolidation						
1	subcollector	12.33	9/9	9	44	56
11	subcollector	20	24/24	22	17	83
12	subcollector	27	30/30	26	19	81
29	subcollector	29.5	25/25	30	0	100
31	subcollector	22.3	26/26	26	0	100
No rice crop consolidation						
Ext.1	collector	5.5	1/2	3	0	100
3	collector	9.25	1/6	7	14	86

4.2 Saving irrigation water and operational costs

Figure (8.9) shows the total irrigation water amounts during the rice season for the modified and the conventional collectors. It is observed that the amount of irrigation water used for modified system are less than the amounts used for conventional system. The average amount of irrigation water used for the modified system is 4298 m^3/fed and 7545 m^3/fed for conventional collectors. This means that the modified drainage system saves about 43 % of the irrigation water comparing with the conventional one.

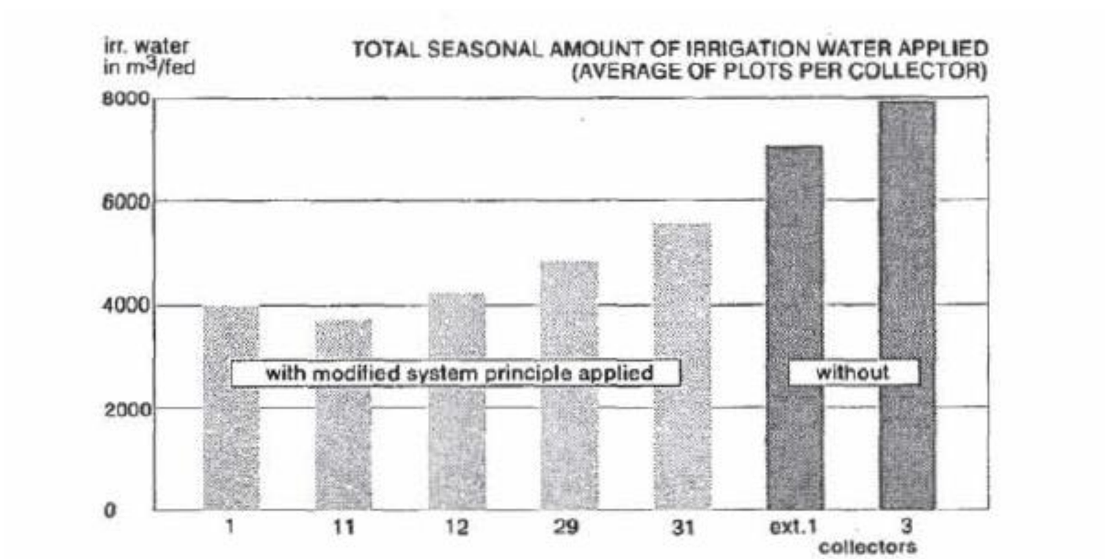

Fig. (8.9) Irrigation water applied with and without modified system principle.

Fig.(8.10) shows the costs of fuel for pumps owned by farmers and the cost of renting irrigation pumps including fuel. Although these two amounts cannot be compared with each other in a strict sense, they reflect the actual expenditures of the farmers during the season. The total costs of renting the pump was 113 LE/fed/season for farmers using controlled drainage and 197 LE/fed/season for the conventional drainage.

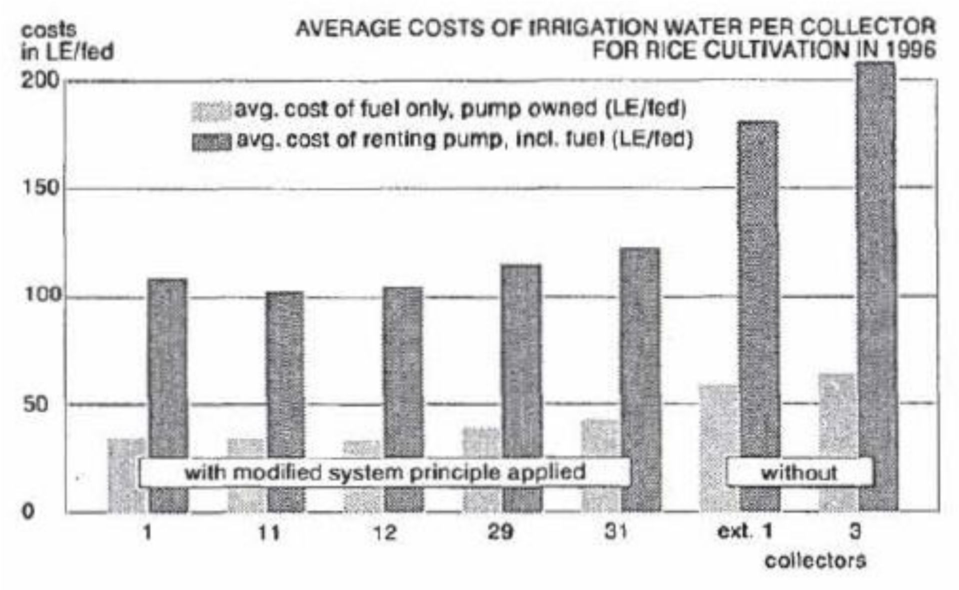

Fig. (8.10) Comparison of some of the costs of irrigation water.

The costs of fuel for privately owned pumps ranged between 30-37.5 LE/fed/season with an average of 33.75 LE/fed/season for rice cultivation with controlled drainage and ranged between 56-62.5 LE/fed./season (average 59.25 LE/fed/season) for rice cultivation with the conventional drainage system.

The difference in expenditure to obtain irrigation water to achieve a satisfactory rice crop was approx. 43% lower than with controlled drainage.

Table (8.5) Rice Yields during 1994 and 1996 and water use in 1996.

Collector number	average 1994 rice yield by farmers recall in kg/fed	avg.1996 rice yield kg/fed (**)	avg. total m^3/fed/season irrigated in 1996
Agreed to rice crop consolidation			
1	2640	2611 (6)	4104
11	2630	2441 (5)	3617
12	2710	2756 (5)	4103
29	2100	2544 (5)	4424
31	2600	2731 (3)	4762
No rice crop consolidation			
Ext.1	-	2016 (1)	7140
3	-	2348 (1)	7956

** in brackets is number of fields from which samples were taken.

Conclusion

The results of the first season of using controlled drainage with the modified drainage system principle (collector-subcollector design) are very positive. Farmers were organized on voluntary basis In groups along small subcollectors to consolidate crop cultivation to rice only in the catchment of the subcollector. Farmers clearly observed the savings in expenditures to the reduced amount of irrigation water applied. No significant major difference was observed in yield in areas with and without controlled drainage, nor were other detrimental effects observed. This confirms the findings of work done during the period 1980-1988.

A major achievement was the methodology followed in establishing the Collector User Groups. An existing organisation that had the trust of the farmers already, essentially organized the CU Groups.

Farmers of adjacent areas have expressed interest in performing similar experiments in their areas.

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(Case Study 2B): MODIFIED DRAINAGE SYSTEM FOR RICE GROWING AREAS: A TOOL FOR WATER SAVING.

By *Dr Hussein El Atfy**

1. INTRODUCTION

In Egypt, rice is cultivated annually in about 420,000 ha in the Nile Delta. It is included in summer cropping pattern, which also includes cotton and maize as main summer crops in a two or three year's crop rotation. Meanwhile the agricultural area is about 3.45million ha located mainly in the Nile Delta and the Valley, with cropping intensity of 200% .

The tile drainage system implemented in Egypt is a composite of the gridiron type consisting of laterals and main collector drains. The area served by one collector drain varies between 20 to 100 ha depending on the topography, field size and layout of main irrigation and drainage systems. (Fig.8.2). There is usually more than one crop served by one collector drain at the same time. Meanwhile, the crops change their locations from one year to the other according to the crop rotation. The drainage criteria are based on the most important crop grown in the area (cotton). The design rate for collector drainpipe is 3 mm/day for rice growing areas. This rate was increased to 4 mm/day to enable adequate drainage condition for the dry-foot crops (Amer et al. 1990).

In spite of this increase in the drainage rate, water management problems occur in areas where rice is cultivated along with “dry-foot crops”, (Abdel Dayem and Ritzema, 1987). Some of the rice growing areas already have the conventional drainage ystems. As rice is the only crop with water standing on the subsurface drainage systems, consequently, high irrigation losses occurred in the drained rice fields.

To save irrigation losses farmers are inclined to block the collector drain pipes at the nearest manhole with whatever is available, i.e. mud and straw, within the rice fields to reduce the losses. This unauthorized interference often causes serious damaging effects on the drainage system and the other crops in the upstream of the blocked section. The blocking objects (man-made plugs) often slip into the pipes causing serious maintenance problems. Meanwhile, blocking the pipes causes excessive pressure in the drain pipes. It may cause water logging and salinization problems in the upstream fields.

Dr. Hussein El Atfy, former Minister of Water Resources and Irrigation, Former Senior engineer at DRI, Cairo, Egypt. He obtained WATSAVE Award (ICID) , 1999

In order to avoid unnecessary excessive drainage from the rice fields, to ensure safe performance of the drainage system, and to translate these farmers' practices into technically sound and environmentally safe subsurface drainage system, it was necessary to modify the layout and the design of the conventional drainage system. So, the concept of the modified layout has been introduced in the rice growing areas.

2. Concept of Modified Drainage System

The main features of this concept are to restrict the outflow from the areas cultivated with rice, which result in saving irrigation water and to enable normal drainage conditions for the remaining areas (cultivated with "dry-foot" crops). It is based on the crop consolidation system, where crops are grown in fixed boundaries, which has been practiced in Egypt since 1960.

The modified layout (Fig. 8.3) consists of a main collector drain with several sub-collector branches. The design criteria within a sub-collector area (e.g. depth and spacing of the lateral drains) remained unchanged as they are still based on the growing conditions of the most important "dry-foot" crop (cotton). Each sub-collector coincides with one crop consolidation unit and is equipped, at the junction with the main collector, with a closing device to regulate the sub-collector outflow.

The new concept was tested on a pilot scale at several locations represented a major rice areas in the Nile Delta from the point of view of saving irrigation water, avoiding unnecessary excessive drainage, soil salinity and water logging, evaluating cost improving soil environment.

A monitoring program to study the water management practices, validity and reliability of this system was carried out, in experimental fields for six successive years 1984-1990. Then, a large scale monitoring areas in farmers' fields 1995-1997, was implemented to verify the previous findings and test the applicability of the (controlled) modified drainage system Fig. (8.7).

3. Monitoring Program

The principles of the modified layout were tested on a pilot scale at several locations each representing a major rice-growing area in the Nile Delta. The objectives of the monitoring program were to obtain a better insight into (El Atfy et al., 1990):

• The reliability of the crop consolidation maps;
• The effects of the water management practices on crop production and soil salinity;
• The effects of the water management practices on the performance of the subsurface drainage system;
• The operation and performance of the closing devices in the modified drainage system.

The investigations were conducted at three levels, namely: (1) fully controlled experiments at three experimental field stations; (2) in-depth studies in farmers' fields; and (3) large-scale monitoring programs in the pilot schemes. At each location, the soil and hydrological characteristics as well as the farmers' practices were assumed to be identical for the adjacent modified and conventional areas, the only difference being the restricted outflow of the sub-collectors of the units in the modified system cultivated with rice. The controlled experiments were conducted in Zankalon (East Delta), Sakha (Middle Delta) and King Osman (West Delta). The studies in the farmers' fields were conducted in three pilot areas:
Mashtul (110 ha), which is part of the first pilot scheme, Mahmoudiya, an area of around 1600 ha in the Eastern in Nile Delta, in Nashart/Roda, which is located in the Middle Delta, and in Balakter (50 ha), which is a part of the Balakter scheme (4000 ha) fig.(8.8).

4. Results and Discussions

4.1 Cropping pattern and intensities

The crop consolidation is the backbone of the modified system. The actual cropping patterns in two project schemes were compared with the crop consolidation maps on which the design of the subsurface drainage system is based. It can be concluded that the crop consolidation maps are a sound and reliable basis for the design of the modified layout. The required information is easily obtainable at the agricultural departments at district level.

The liberalization of cropping pattern and no imposing of crop rotation which is recently introduced - represent the main constraint for implementing the modified drainage system.

4.2 Irrigation water applications

Rice fields under modified drainage conditions require less irrigation water to maintain the same height of ponding water because of the restricted outflow of the subsurface drainage water. During the summer seasons, fully controlled water management experiments were conducted in modified and conventional units in three experimental fields, in addition to farmers fields, where traditional and improved irrigation system are established. All units were cultivated with rice under optimum water management conditions. If the average height of the standing water dropped below 5 cm, irrigation water was supplied to a level of 9 cm. The irrigation water supply, as well as the daily drop in standing water, was measured in both systems.

The differences in water use are due to the different hydrological conditions (DRI, 1986a, 1986b, 1997). Nevertheless, in all three areas, the fields with a modified layout required around 40% less irrigation water than the conventional units (Fig.8.11). In the farmers' fields, however, the daily drop in the modified units was again less than the daily drop in the conventional units, the difference being between 22 and 35%.

Fig. 8.11 shows the water applied during rice season for the modified and the conventional systems in experimental fields, traditional irrigation fields, and improved irrigation fields. The average amount of irrigation water used for rice modified system area is 8000 m^3 /ha, 10000 m^3 /ha, and 8 000 m^3/ha, respectively. This compared with average irrigation water used for rice conventional area 14 900 m^3/ha, 18 000 m^3/ha, and 14 000 m^3/ha in experimental, traditional and improved irrigation areas, respectively.

It can be concluded that the average saving in irrigation water supply to the rice plots in the modified system is around 30-40%. As a consequence, farmers in the modified system need irrigation water application less frequently, which also implies savings in operational activities.

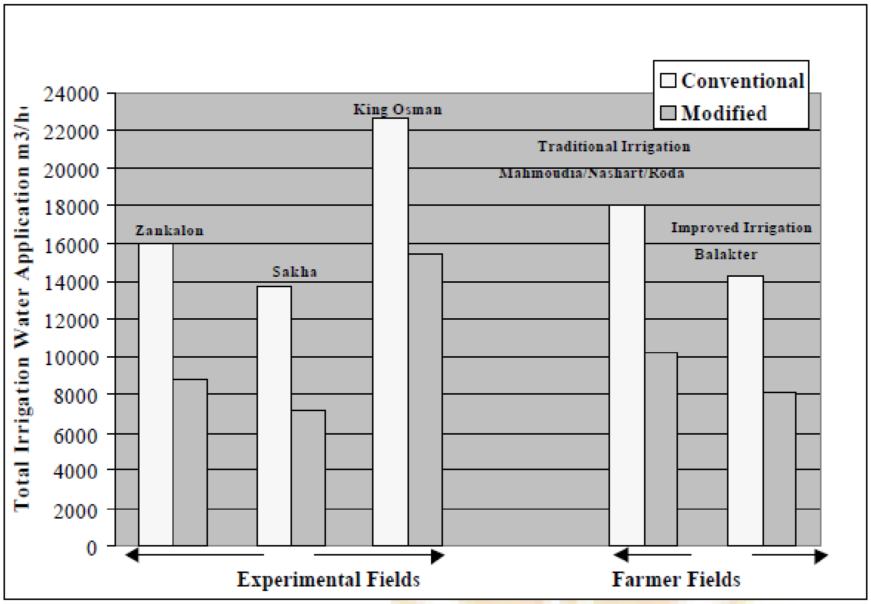

Fig. 8.11. Total Irrigation Water Application to rice fields

4.3 Collector discharges and salinities

Discharges were measured at the outlet of the collector drains and simultaneously the salinity of the drainage water. Each year the measurements started in June and continued until October, covering the total summer season. Each collector was measured at least once a week (DRI, 1989b).

The analysis of the individual collector drains (DRI, 1985, 1987b, 1989a) showed that in the modified systems the 90% cumulative discharge rate was independent of the rice intensity in the drainage area. This is in contrast to the conventional units, where the average 90% cumulative discharge rate increased from approximately 2.0 mm/day for collector with more than 60% rice. The discharges from collectors with less than 20% rice were in the same order of magnitude as the discharges from the modified collectors, although in the latter, the rice intensity was much higher. It is clear that the introduction of the modified system reduced the discharge through the collector drains. As a consequence, the design rate for collector drain (3 mm/day) can be reduced even further, as the discharge rate at 90% cumulative frequency did not exceed 2.3 mm/day.

4.4 Performance of closing devices

The function of a closing device (Figs. 8.4 & 8.5) is to restrict the outflow of a sub-collector serving an area cultivated with rice. Four types of closing devices were tested namely the steel flap gate, the steel sliding gate, the aluminum disc plug, and the wooden plug (DRI, 1985). The steel flap gate emerged as the most promising device and was tested on a large scale. A total of 31 flap gates were installed during the spring of 1985 and their performance was monitored during the following summer season (DRI 1986b). The performance was evaluated by the difference in water level between the upstream and downstream manholes and by regular visual inspection. The performance of 73% of the gates was rated as good, bad performance being mainly due to difficult installation conditions (submerged outlets of the collector pipes). In the spring of 1988, the same prototypes were installed in the other project area (Nashart). The best performance observed was by the steel flap gates and, to a lesser degree, by the wooden plugs (DRI, 1989b). Although some leakage occurred, the outflow from sub-collector areas cultivated with rice was considerably reduced. Neither the sliding gates (too much leakage) nor the aluminum disc plugs (pushed out by the water pressure) performed satisfactorily.

4.5 Soil salinity

Soil samples were collected two times during each summer season. The first sampling was done just before the start of the rice season, and the second sampling during harvest. The soil samples were collected from three layers, i.e., the surface layer (0-25 cm), the subsoil surface (25-50 cm), and at drain depth (125-150 cm). The salinity of the saturation extract was measured. To compare the data, the average salinity level over the top 0.50 m of the soil was calculated (DRI, 1989b).

The total amounts of salts removed by the subsurface drainage system were much higher in the conventional units. (Fig. 8.12). This can be attributed to the higher irrigation water requirements in the conventional units and the fact that the salinity of this irrigation water is relatively high due to the occasional reuse of drainage water in periods with water shortages.

4.6 Crop yield

Samples of the rice and maize crops were taken from the same locations used for the soil samples. Data on the yield of cotton were obtained from the Agricultural Cooperatives. The yield of the individual fields was characterized by high variability, which is not surprising because of the many factors that influence crop production. For both the conventional and the modified units of each area, the average yields were calculated (DRI, 1989b, 1997). Although there is some variation between the seasons and between the areas, no significant differences could be established between the modified and the conventional units (Fig. 8.13).

5. Cost Comparison Between Modified and Conventional System

For the two large pilot projects (Mahmoudiya 1 and Nashart), both, conventional and modified design were made. On the basis of unit prices, the differences in construction costs between the two systems were calculated (DRI, 1985, 1986b). The total length of pipes in the modified system is greater because of the introduction of sub-collectors which, together with the installation of closing devices, leads to extra costs. On the other hand, the lower design rate implies a reduction in the size of the collector pipes as compared to the current design norms and thus leads to cost savings. Savings in maintenance costs and the benefits of a more reliable system have not been considered in the analysis.

Mahmoudiya 1 was the first area where the modified system was introduced on a large scale; it was constructed in 1982. Based on 1983 prices, the costs of the modified system were 12% higher than those of the conventional system. This difference can be attributed to:

• The relatively small size of the sub-collector units in the modified system;
• The design rate for the collector drains in the modified system was 3 mm/day, which is quite high compared with the design rate for non-rice areas (2 mm/ day). The design rate for the conventional system was 4 mm/day.

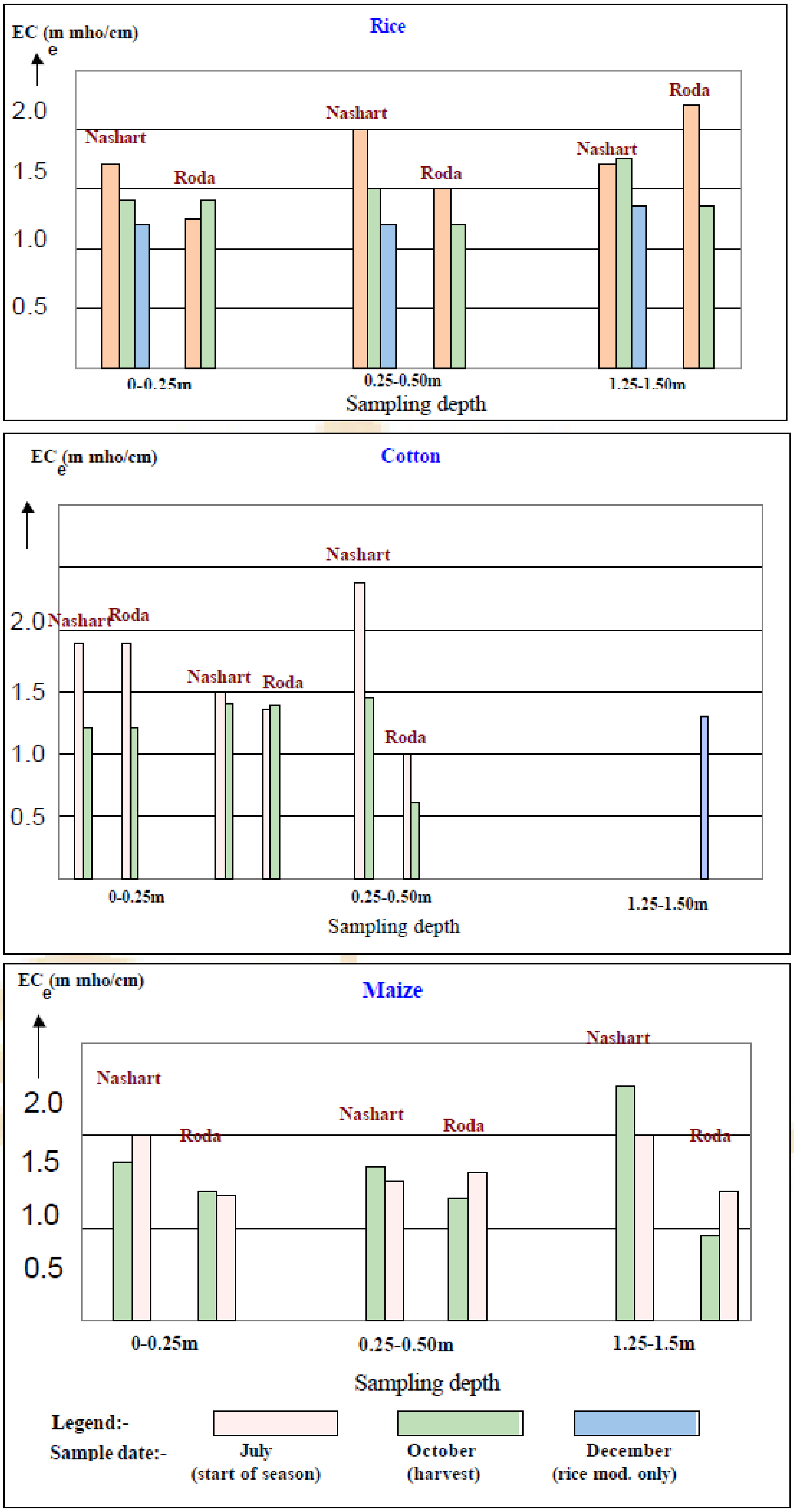

Fig. (8.12). Soil salinity levels in farmers fields (Roda and Nashart).

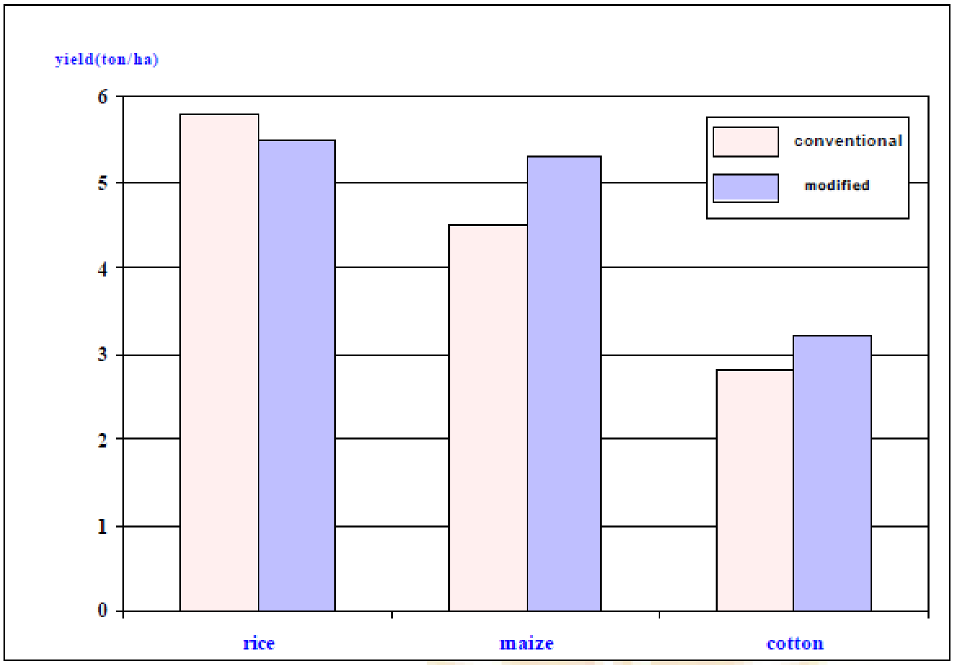

Fig. 8.13 Overall average crop yield.

6. Conclusion & Recommendations

The modified system, which is based on the crop consolidation scheme, was tested at several locations in the Nile Delta. After the principles were studied in experimental fields, detailed investigations were carried out in farmers' fields and followed-up by large-scale monitoring programs. The study covered a nine years period running from 1983 to 1999. The introduction of the modified layout of the subsurface drainage system in rice-growing areas in the Nile Delta resulted in:

• Savings in irrigation water up to 30%. This irrigation water would otherwise be lost through the subsurface drainage system: the difference in drainage rates from rice fields between the conventional and modified drainage system amounts of 1 to 3 mm/day over a growing season of approximately 100 days;

• Protection of crops other than rice from the damaging effects of improperly blocked conventional collector drains;

• These benefits were obtained without any negative effects on either soil salinity or crop yield and with increase in costs range to (6-12%) compared with the conventional system in construction.

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Case study (3): IRRIGATION WATER SAVING BY MANAGEMENT CONCEPTS OF EXISTING SUBSURFACE DRAINAGE SYSTEM

*By: Dr. M.A. Wahba et al.**

A new, management concepts for existing subsurface drainage systems have been developed to improve irrigation water use efficiency. The management concepts were to change the effective drain spacing and effective drain depth by applying, easily adoptable management measures. These management options were compared with the conventional “non management” by applying the DRAINSMOD-S model to the western Delta of Egypt.

1. Existing Subsurface Drainage Systems

In Egypt more than 3.0 million ha of agricultural land are covered by intensive subsurface drainage systems. If we consider the design daily drainage rate of 4.0mm/day and this occurs for 180 days of the year, the total drainage water from all these drained areas will be about 7.2 BCM/year. This provides a large opportunity for more irrigation water saving by proper management of these existing systems.

The subsurface drainage systems consist of lateral pipes, connected to collector pipes that outfall into surface drains. After the construction of subsurface drainage systems, no formal management is implemented and the systems are left to flow continuously. Sometimes farmers try to control the amount of drainage by blocking drains. These sections are informal, untested and jeopardize the overall function of the system. Simple easy to implement measures are required that farmers can implement.

14.

2. Subsurface Drainage Management Concepts

The design of subsurface drainage aims to find the best spacing between drains and the depth of drains which maintains the water table at a suitable depth for crop root development based on soil properties, irrigation data and crop types. After the system is implemented the drain spacing and depth cannot be changed, even though the system parameters such as crop type, crop root development, weather, quantity and quality of irrigation water, and available water resources are constantly changing.

**Dr. Mohamed Abdel Monem Wahba, Assistant professor Deputy, Director of (RCTWS, MWRI, Cairo, Egypt see ref.).*

The management concepts developed for Egyptian conditions are based on controlling the water table by managing the *effective* spacing and *effective* depth during specific stages of the growing season. In this way it is possible to make the subsurface drainage a dynamic system to match the dynamic crop production parameters.

A flow chart of the subsurface drainage management concepts is shown in Figure (8.14) and a description of the concepts is as follows:

2.1 **Changing the Effective Drain Spacing**

The changing of the effective drain spacing depends on doubling the *effective* drain spacing from L to 2L during the crop growing season. This can easily be applied by blocking alternate drains, when the blockage is removed the *effectiv*e spacing returns to its original L. This management can be applied to the whole season or in two stages as follows:

Stage 1*: change the effective drain spacing from L to 2 L (Fig. 8.15).
How: Close alternate drains.
Time of application: Beginning of the growing season to about halfway through the season.
Applied irrigation water: X% reduction of irrigation water (suggested reduction by 5% to 20% depending on prevailing condition and testing).
***** This stage can be applied for one irrigation event, part of the growing season, or for the whole season, depending on prevailing conditions.

Stage 2: Return the *effective* drain spacing from 2L to L (Fig. 8.16).
How: Unblocking the drains
Time of application: End of stage 1 to the end of the growing season.
Applied irrigation water: Standard irrigation.

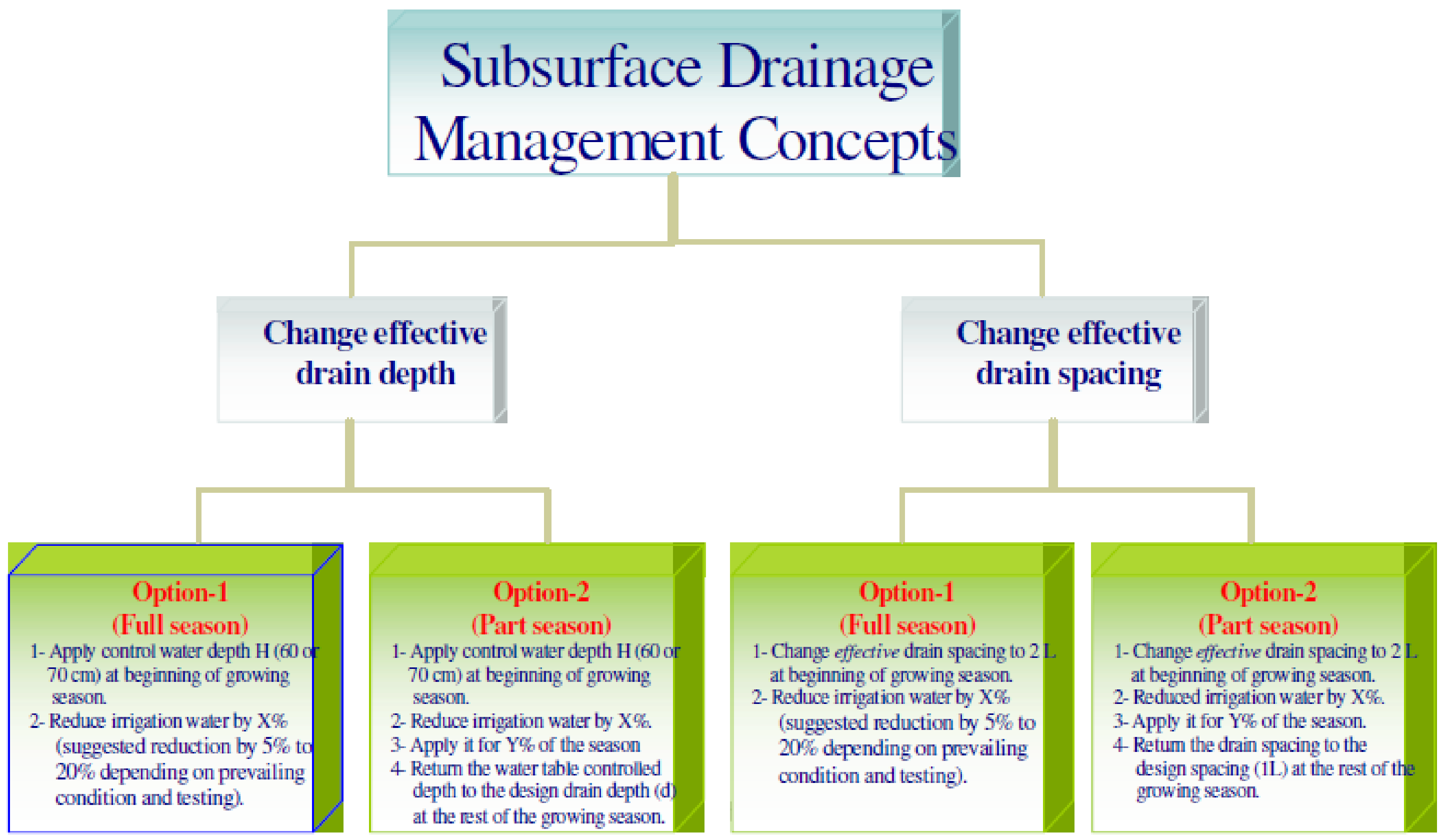

Fig. (8.14) Flow chart for subsurface drainage system management concepts

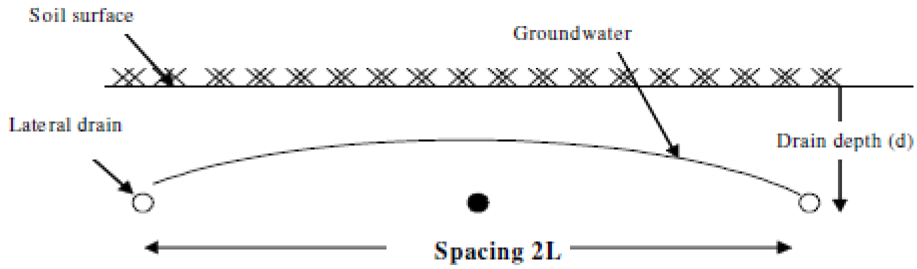

Fig. (8.15) stage 1 of changing drain spacing management

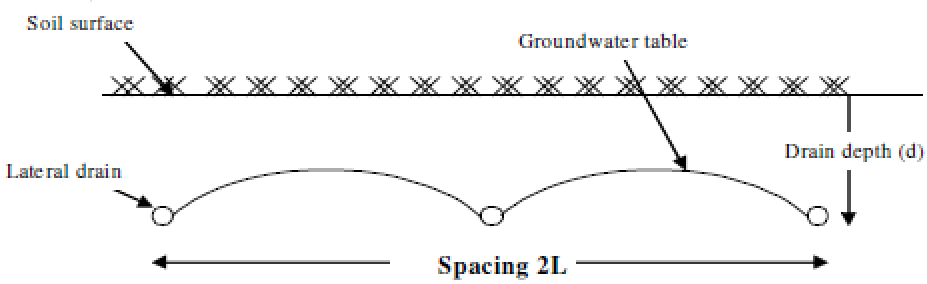

Fig. (8.16) stage 2 of changing drain spacing management

2.2 Changing effective drain depth

The Changing of the effective drain depth depends on controlling the water table depth during the cropping season. This can easily be applied by using a weir across a sump or riser on a drain. This management can be applied for the whole season or in two stages as follow:

Stage 1*: Controlling water table depth (Figure 8.17).
How: By using weirs or risers at depth 60 or 70 or 80cm below ground level.
Time of application: Beginning of the growing season to Y% of the growing season.
Applied irrigation water: X% reduction of irrigation water (suggested reduction by 5% to 20%, depending on prevailing condition and testing).
***This stage can be applied for one irrigation event, part of the growing season, or the whole season, depending on the prevailing conditions.

Stage 2: Allow free drainage to the design drainage depth (Figure 8.18)
How: By adjusting/removing the control device.
Time of application: End of stage 1 to end of the growing season.
Applied irrigation water: Standard irrigation.

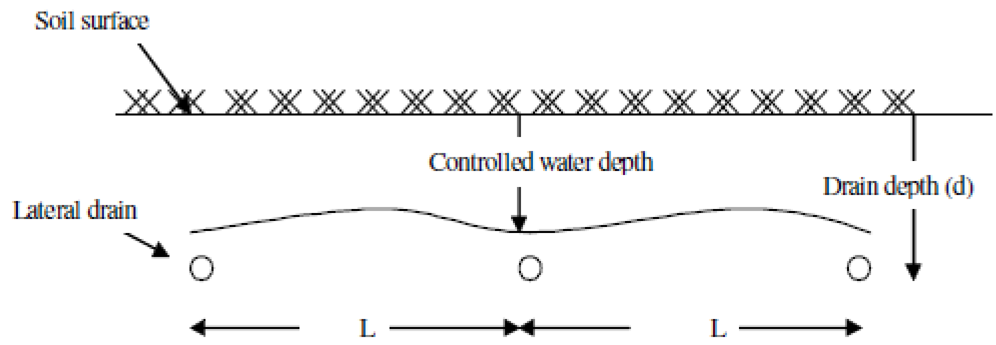

Fig. (8.17) stage 1 of changing the water control depth management

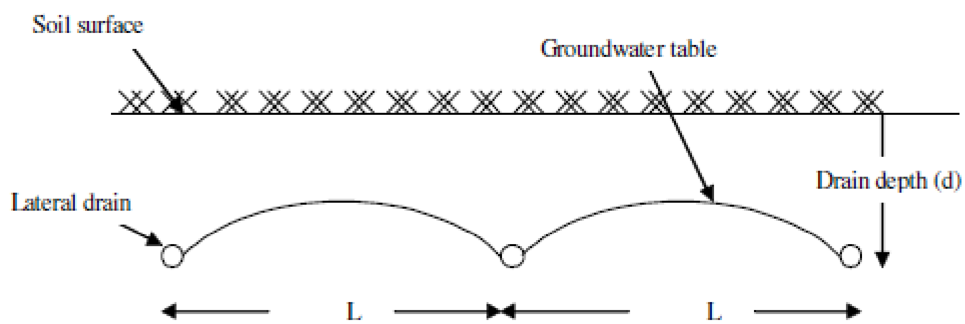

Fig. (8.18) stage 2 of changing the water control depth management

3. Application of the Subsurface Drainage Management Concepts

The groundwater table management simulation model, ***DRAINMOD-S***, was used to evaluate the management concepts described above. The model has been tested using field data from Maruit experimental station in the Western Delta of Egypt for three cropping seasons; maize 1999, wheat 1999/2000 and maize 2000. Two ground water table managements (conventional drainage and controlled drainage) were applied in the study area. The recorded data included daily groundwater table depth, drain outflows during flow events, soil salinity to depth of 1.20 m from the soil surface (0.30 m interval), and relative crop yield for each applied crop. The reliability of the model was evaluated by comparing measured and predicted values of daily groundwater table depth, cumulative outflow based on total monthly outflow, soil salinity during each season, and relative crop yield.

Good agreement was found between the measured and predicted data. The model showed the potential for long-term simulation and planning of ground water table management under semi-arid conditions of the Western Delta of Egypt (**Wahba et al, 2002).**

Five scenarios for subsurface drainage management have been developed as options to manage the existing drainage systems (Table. 8.6).

Table (8.6) Scenarios of management concept options

Scenarios	Timing	Management type	Drain spacing (m)	Drain depth (m)	Control depth (m)	Applied irrigation water
E.S	Full season	None	30	1.15	1.15	100%
S.C.F	Full season	Spacing control	60	1.15	1.15	85%
D.C.F	Full season	Depth control	30	1.15	0.6	80%
D.C.P	Part season	Depth control	30	1.15	0.6	85%
	Part season	Free drainage	30	1.15	1.15	85%
D.C.P + S.C.F	Part season	Depth / spacing control	60	1.15	0.6	80%
	Part season	Spacing control	60	1.15	1.15	80%

E.S: *Existing drainage system, S.C.F: Spacing control Full season, S.C.P: Spacing control Part season, D.C.P: Depth control Part season, and D.C.F: Depth control Full season.*

The ***DRAINMOD-S*** model was used to simulate these scenarios for ten years under the same conditions as the experimental field using a crop rotation of wheat, maize, barseem (alfalfa), and cotton, which is the most common crop rotation in the Nile Delta.

Crop yield was considered as the most practical measure of crop response to water stresses for the purpose of optimizing the water management system. Thus, the selected scenarios were evaluated by water use efficiency in terms of crop yield (g/mm) and how much irrigation water was used.

The relative crop yield predicted by the DRAINMOD-S is given by the following equation:

$$RY = RYw * RYd * RYp * RYs \qquad (1)$$

Where:
RY = overall relative yield for a given season
RYw = relative yield that would be obtained if only wet or excessive water stresses occurred

RYd = relative yield that would be obtained if only drought stresses occurred
RYp = relative yield that would be obtained if the only stresses are due to planting delays
RYs = relative yield resulting from the soil salinity.

The relative yield may be expresses as:

$$RY = Y/Yo \qquad (2)$$

Where:
Y = measured or observed yield for a given season
Yo = long-term average yield that would result from an ideal circumstance

The predicted yield will be calculated from equation 2 using the data of the predicted relative yield from the output of the simulation and the average crop yield for the applied crops in the study area. The crop yield per m^3 will be calculated using the values of predicted yield and the amount of irrigation water used.

3.1 Water use efficiency

The results of the long term simulation (10 years) for wheat are shown in Figure (8.19).This shows that the average water use (g/mm) for wheat was lowest with conventional irrigation and drainage at about 1.35 g/mm. The highest water use was obtained with D.C.P + S.C.F and D.C.P scenarios, which was about 1.6 g/mm, and a 16% increase on the conventional. The other scenarios had a value of 1.53 g/mm. The increased production per unit water did not result in any overall yield reduction in any of the scenarios.

The water use for the maize crop for all scenarios is shown in Figure (8.20). The lowest water used efficiency obtained was also with the conventional scenario, which was about 1.16 g/mm, and the highest value was about 1.51 g/mm with D.C.P scenario, an increase of about 23%. The average relative yield for maize over the 10 years was 94% with conventional and ranged from 98% to100% for the other scenarios. This shows that not only the productivity per unit of water can be increased but also the overall yield per unit land area.

The water use efficiency for cotton is shown in fig (8.21). The lowest water use efficiency was the conventional at about 0.35 g/mm. The highest value was about 0.44 g/mm, indicating a 20% increase in yield per unit water applied.

3.2 Potential water saving with the concepts in Egypt

The average irrigation water used for each crop during the 10-year simulation is given in Table (8.7). All the crops used less irrigation water with the management scenarios compared to the conventional irrigation and drainage management. The results indicate that it is possible to save about 577 - 770 m^3/ha for wheat, 1071 - 1280 m^3/ha for maize, 455-603 m^3/ha for alfalfa and 1117 - 1476 m^3/ha for cotton with the proposed management concepts.

The total area which covered with subsurface drainage system is expected to reach more than 3.0 million ha by the year 2017. For analysis we have taken only the Western Delta area as representative of the experimental area on which the model calibration is based. The area covered by subsurface drainage in the Western Delta is approximately 0.4 million ha. The results of the drainage management scenarios were applied for the Western Delta area, with the assumption that the crops grown have the same distribution as the national average. The analysis shows that over a two year rotation the water saving is considerable, ranging from 62 million m^3 with cotton to 132 million m^3 for maize (Table 8.7). In total the water saving could be in the order of 379 million m^3 over a two year crop rotation.

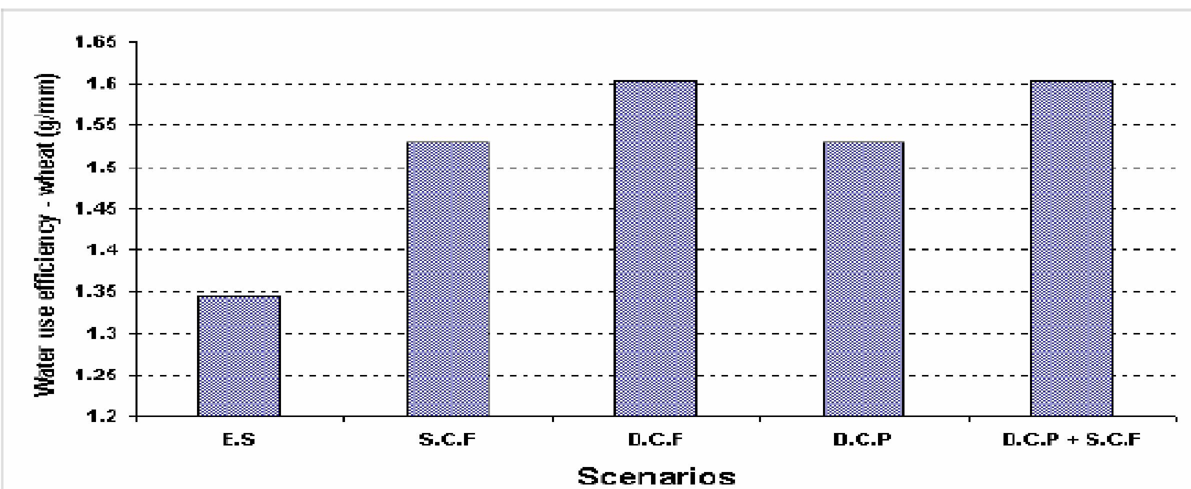

Fig. (8-19) Average wheat water use efficiency

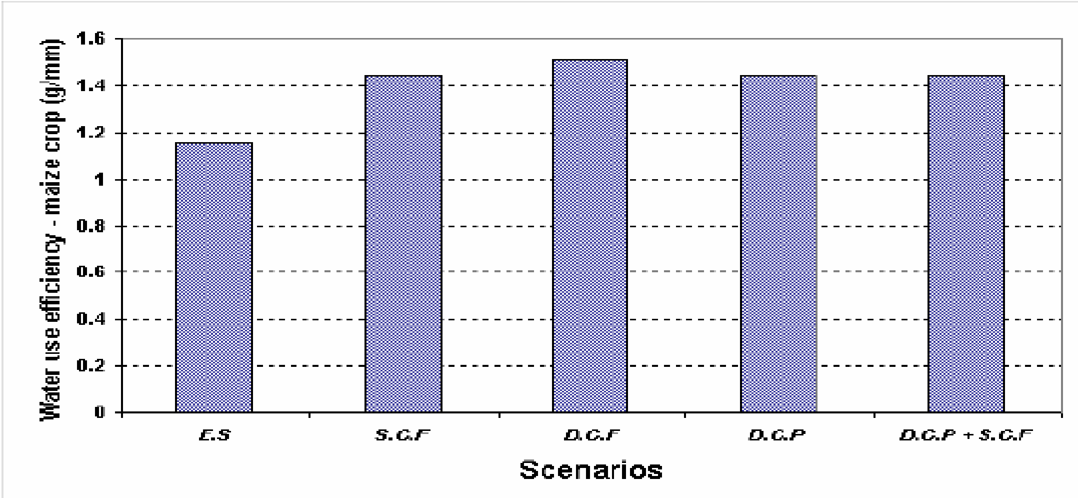

Fig. (8-20) Average maize water used efficiency

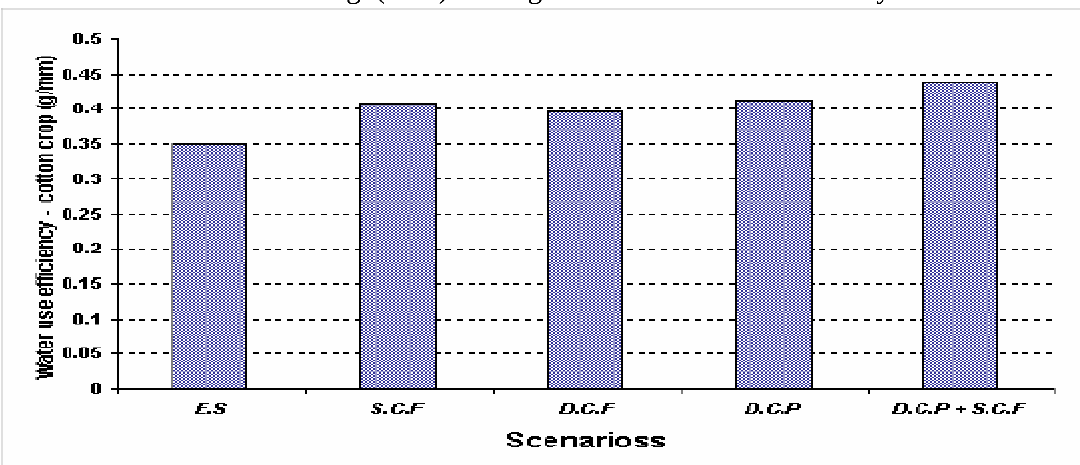

Fig.(8-21) Average cotton water use efficiency

From the above results it is clear that the water use efficiency is improved by subsurface drainage management concepts coupled with reduced irrigation without affecting production. The results show that water can be saved, that can be used elsewhere, whilst production can be maintained and even increased on existing areas.

Table (8.7) Average water use and total water saving for all scenarios (m^3/ha)

Crop	E.S	S.C.F	D.C.F	D.C.P	D.C.P / S.C.F
Wheat	4778	4201	4008	4201	4008
Maize	6406	5433	5126	5433	5126
Barseem (Alfalfa)	3947	3492	3340	3492	3340
Cotton	7394	6277	5918	6277	5918
Total irrigation water saving during the two seasons	-	**3122**	**4133**	**3122**	**4133**

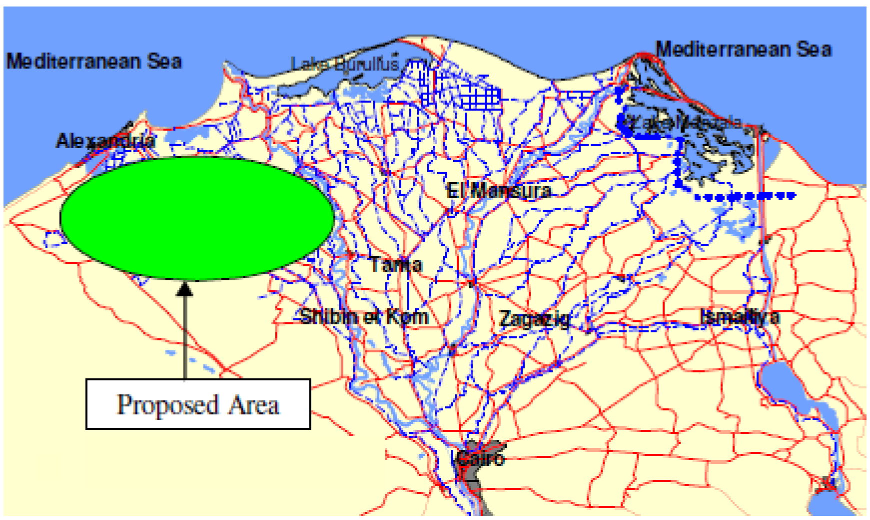

Fig. (8.22) Proposed areas of subsurface drainage system in Western Delta of Egypt

Table (8.8) Analysis of controlled drainage water savings for Western Delta Area

CROP	Crop intensity applied to Western delta (%)	Potential irrigation water saving per crop (m3/ha)	Total saving for Western Delta area (M m3)
Barseem (Alfalfa)	40	529	85
Wheat	37	674	100
Maize	28	1178	132
Cotton	12	1297	62
Total potential water saving			**379**

*Derived from data in Egyptian National Agricultural library, 2001

4. Conclusion

When controlled drainage is implemented irrigation volumes can be reduced, without sacrificing yields. Application of controlled drainage has the potential to maintain and even increase yields per unit land whilst increasing the irrigation water use efficiency (yield per unit water) by 15 - 20%.

When the potential on-farm water savings by using controlled drainage are applied to large areas then the potential for water saving in Egypt is large. For the Western Delta area of about 0.4 million ha this could amount to about 0.4 BCM over a two year rotation. These water savings can then allow an increase in cropping intensity or irrigation of new lands.

Implementation of subsurface drainage management such as the low cost and easily understood options described in this paper need to be undertaken as part of an integrated approach to water saving. When controlled drainage is implemented then appropriate reductions in irrigation application needs to occur. This will require coordination and training between irrigation authorities, drainage authorities and farmers.

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Case(4) : CONTROLLED DRAINAGE DEVICE

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Controlled drainage aims as integrated irrigation management to save water at the farm level. It is used as a tool to assess water saving resource protection and crop production.

1. Development of the Controlled Device

The controlled device used at the farm level is a simple, cheap and easily manufactured from local, available materials. The device prevents drain flow to the subsurface drainage system when the water table in the field is below a specified depth, and allow drain flow when the water table is above this depth. The specified depth during the crop season could be adjusted.

The designed device is constructed from 90 mm PVC pipe, commonly available locally (fig.8.23). The device is fitted into the end of each field lateral pipe where it meets the collection pipe at access manholes of these subsurface drainage systems. Farmers can thus, fit and maintain the devices themselves. Different lengths of vertical pipe allow the device to control drainage at varying water table depths, either during or between crop seasons.

The cost of the prototype device (materials and construction) may be expensive to the farmer, however if the devices are made in bulk, the unit price would be reduced considerably.

In areas where controlled drainage is applied to the sub-collector (rather than lateral, one device could serve many farmer, which reduces the cost considerably.

2. Field Study: To Predict the Impacts of Controlled Drainage

A field study (fig. 8.24) was carried out in two plots, each approximately 100 m by 100 m, separated by a drainage collector (see fig. 8.25). The plots were irrigated via a small concrete channel with gates to enable the area to be surface irrigated with minimum distribution losses. The area is served by a horizontal subsurface drainage system, consisting of 259 mm diameter PVC collector pipes and 72 mm diameter PVC laterals. Concrete access manholes (diameter /1m) are positioned along the collector pipe where the laterals intercept the collector. The laterals are installed at a depth of 1.2 m and a spacing of 35 m. The drainage system discharges into an open drain at the lower end of the site.

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Two crop seasons were studied at the field site. Maize was grown from June to October and wheat from November to May. Conventional irrigation and drainage management was compared to controlled drainage using weir devices as shown in fig. (8.23) positioned in the access manholes, and by controlling water depth in the main outfall drains. The field site was instructed to enable irrigation water use, drainage flows, soil moisture and salinity, water table depth and crop response to be compared on the two plots.

The management strategies applied to each crop are summarized in the table below:

Table (8. 9) Irrigation and drainage management strategies applied to the field plots*

Plot	crop	Irrigation	Drainage
A	Maize	Conventional	Conventional
	Maize	As above	Controlled drainage with manhole weir at 0.6 -0.7m depth.
A	Wheat	Conventional	conventional
B	Wheat	10% reduction in irrigation application	Controlled drainage with manhole weir at 0.6-0.7 on depth and weir in out fall drain.

*C.L. Abbot, S. Abdel-Gawad, Ms. Wahba (2001): Field testing of controlled drainage, and verification of the wasim simulation model (Report OD /TN102) H.R.Walling ford.

3. Main Conclusions from Maize and Wheat Season

Maize season

- Drain flow is reduced on the controlled drainage plot.
- Water table depths through the season were a bit higher on the controlled drainage compared to the conventional drainage
- The crop yield on the controlled drainage was 4% higher than on the conventional drainage.
- Drain flow was significantly reduced, under controlled drainage.

Wheat season

- Water table depth through the season was higher on the controlled drainage
- Drain flow was again less on the controlled drainage device at 0.6-0.7m depth.
- The wheat yield was 9% higher on the controlled drainage, while 9% less irrigation water was applied.
- An irrigation water saving was achieved on the controlled drainage without decreased crop yield.

In conclusion although the field work gave an indication of the impacts and benefits of controlled drainage, application to larger areas with farmer management is necessary.

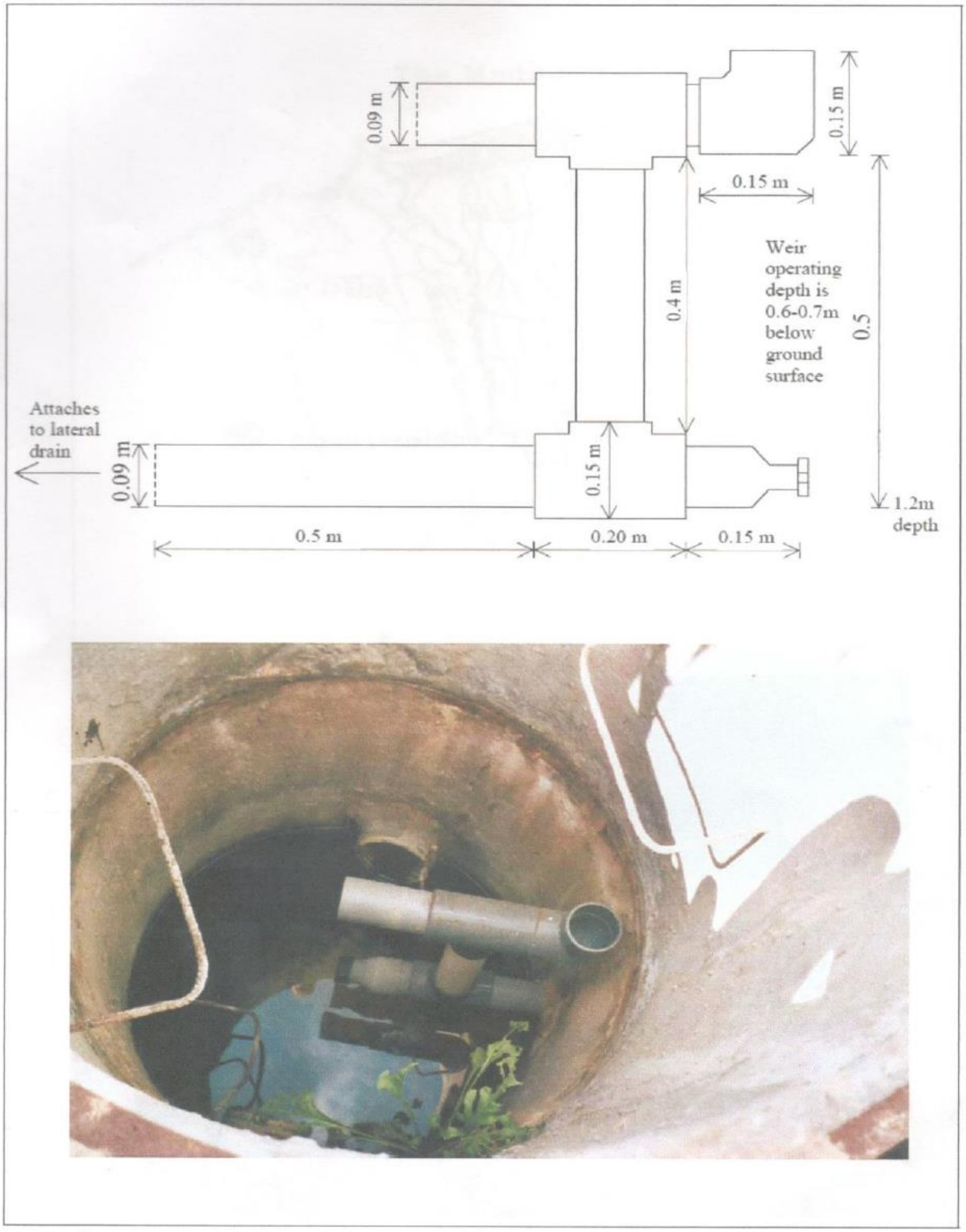

Fig .(8.23) Prototype controlled drainage device, showing design details and location in subsurface drainage access manhole.

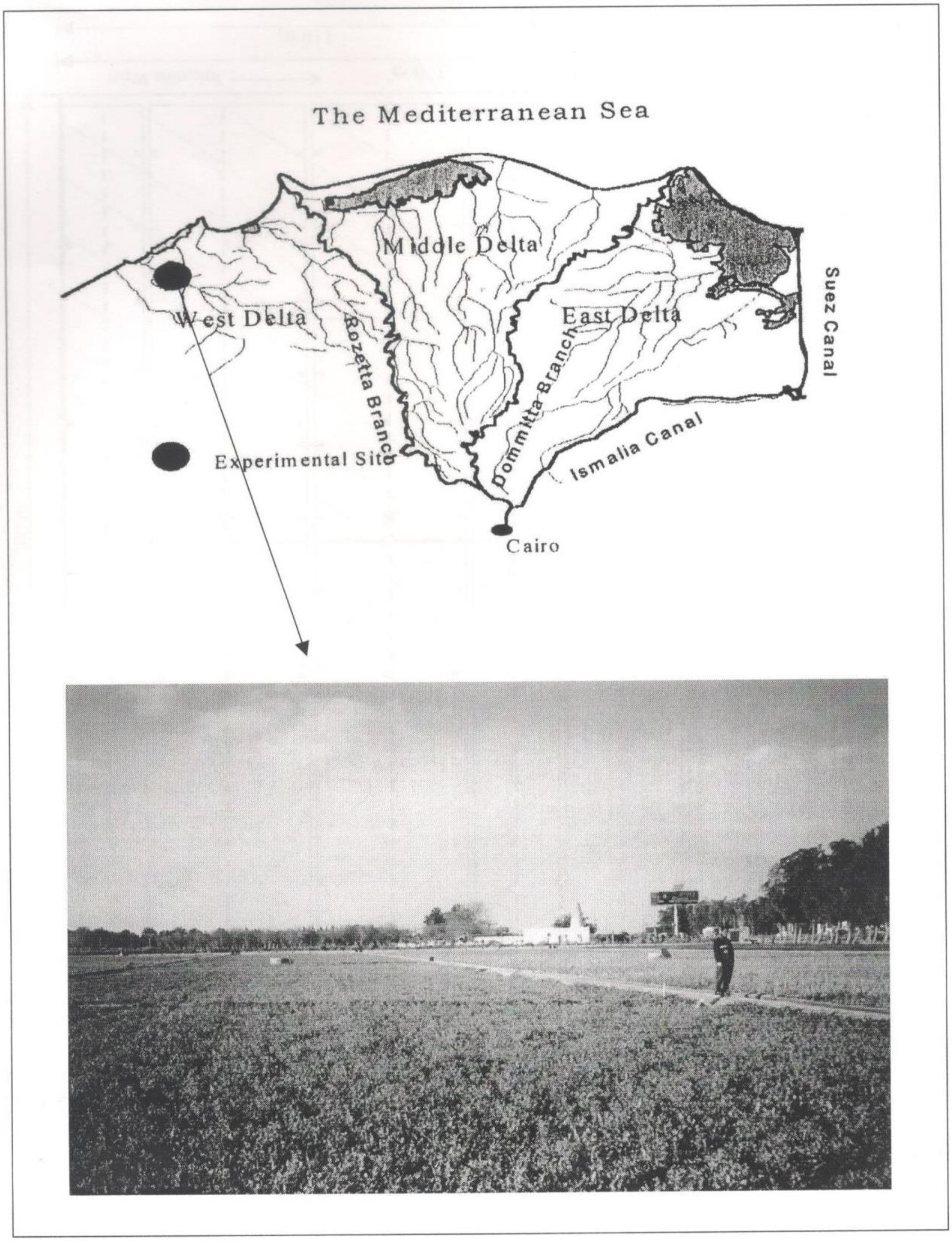

Fig. (8.24) Location of the Mariut field site

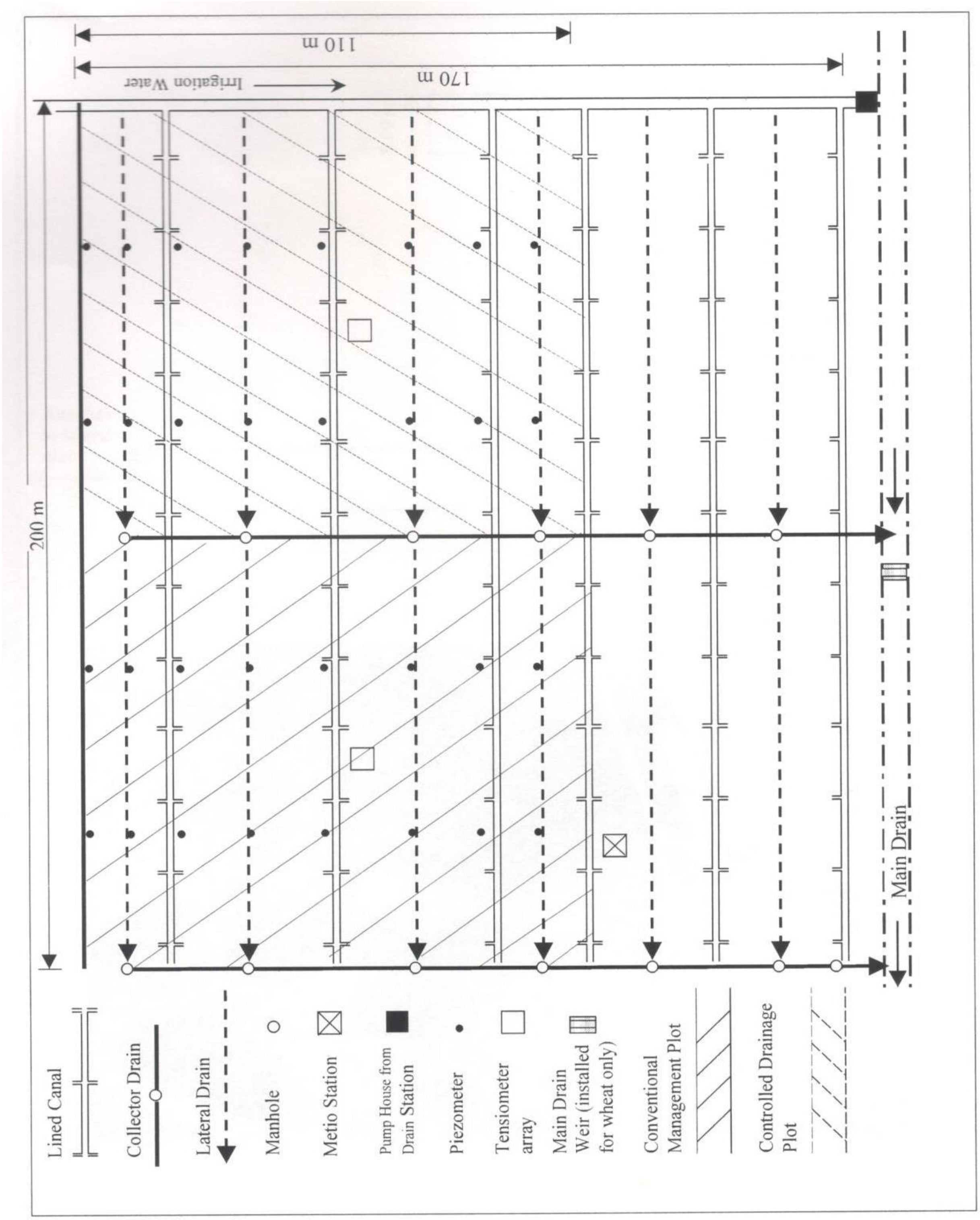

Fig. (8.25) Mariut field site showing irrigation and drainage layout for the plots, and instrumentations installed.

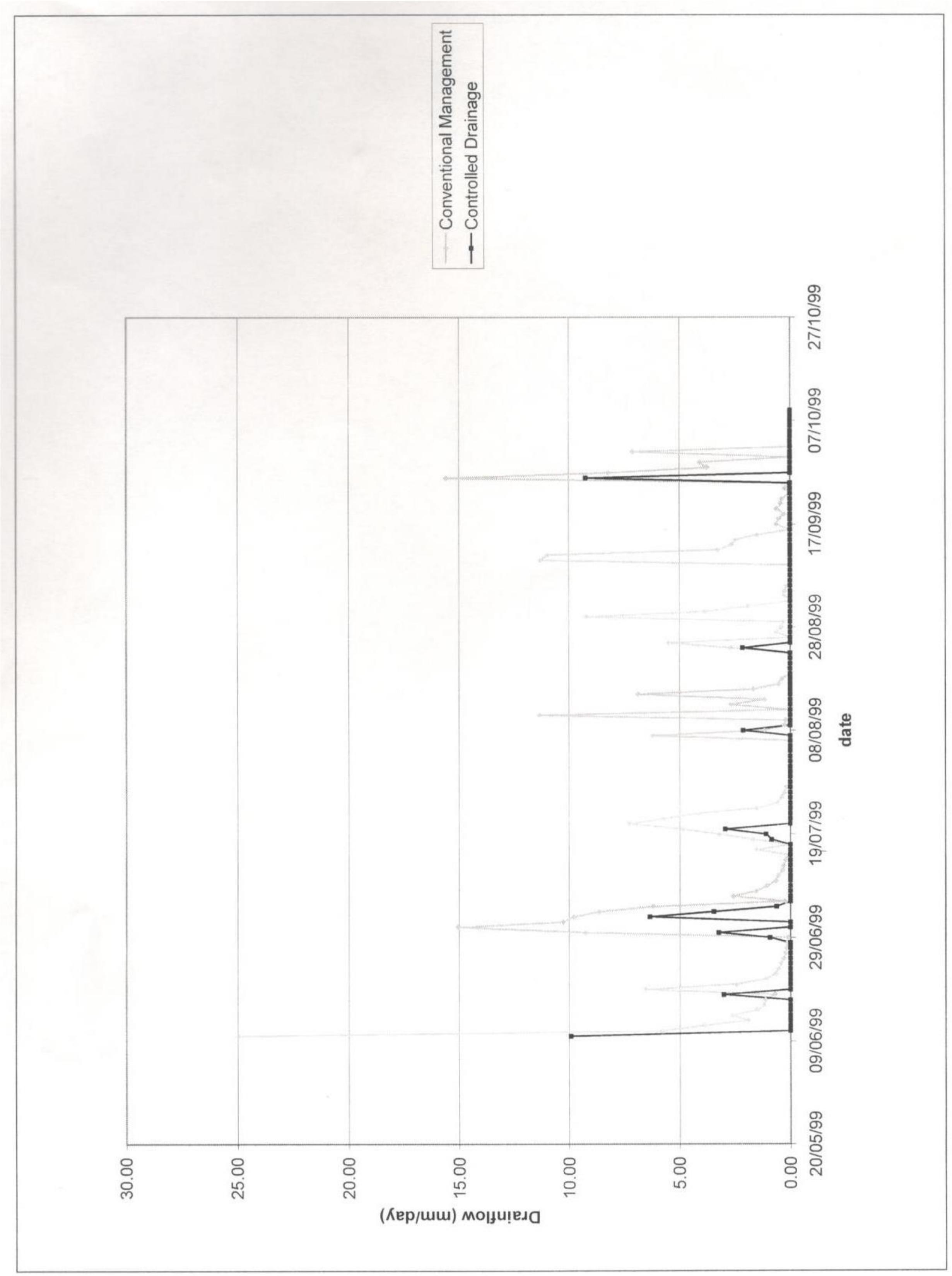

Fig. (8.26) Daily drainflow during the maize season

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Chapter 9

The Way Forward

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THE WAY FORWARD

9.1 Agriculture and Water

Agriculture in Egypt relies heavily on irrigation water from the River Nile. Compared to a century ago, the annual per capita share of fresh water resources has declined by more than 80%. The land itself is in short supply due to population over-growth. The cultivated area person part (0.05 ha) is now among the lowest in the world. Much land is being taken out of the agricultural sector by increasing urbanization. This will have a negative effect on the sustainability of natural resources.

Mismanagement of water resources in the agriculture sector, over-irrigation, and the use of low quality water are all leading to rapid land degradation due to salinity, alkalinity and water logging problems. Nowadays, around 30% of the world, irrigated productive lands are affected by salinity.

It is evident that opportunities for the significant capture of new water are now limited. Most river systems suitable for the large scale irrigation have been developed already. Few major resources of renewable groundwater remain untapped and current resources are subject to over exploitations, with extraction exceeding the recharge rate in many cases.

The irrigated areas will continue to be virtual for food security. To meet increasing demands for food, Egypt is expanding their irrigated areas; however, with decreasing water resources for agriculture, the only water that can be made available for new lands is the water that can be saved from irrigating old lands.

Water scarcity is a matter of national concern, not the concern of only one or two ministries; water efficiency and conservation need to be a strategic objectives for all ministries.

There are several constraints and questions that need to be addressed in order to achieve sustainable increases in water productivity. These include:

- What are the technical options for maximizing water use efficiency, including water management options, cropping patterns, variations and agronomic management.

- What integrated water management guidelines are needed under conditions of water scarcity to produce more crops with less water.

- How does the farmer select his/her cropping pattern and inputs to maximize income as well as water productivity. Can this be developed into a general decision support tools.
- How will land use change as climate, markets, trade…etc. change and how can changes of land use be predicted and/or managed to ensure sustainable agricultural productions and livelihoods.
- What are the policies needed to encourage efficient water use and save water in irrigated areas.
- How can marginal-quality water be used before high productivity without degrading the land.

9.2 Suggestions for Sustainable Development and Adoption of Water Saving In Irrigation Agriculture.

The key future challenges include availability and accessibility of fresh water resources due to climate change, energy availability for irrigation, environmental flow requirements, water supply for growing bio-fuel crops and achieving integrated water resources management (IWRM). This requires for innovative scientific and technological solutions using multi-disciplinary approach based on social, economic, political and cultural setting of the country.

There are among success stories, best practices and research studies of water saving in agriculture as introduced in the text chapters. There is a need to explore all these innovations and accelerate the adoption the process of transfer and dissemination of water saving technological and management skill from professionals and to the stakeholders, farmers, irrigation, drainage management organizations.

- Water management it is very importance to continue with the efforts of increasing irrigation efficiency so as to expand the irrigated area using available water resources.
- Matching irrigation supply and demand comes in the list of priorities since it is one of the major water saving measures and is very low cost. All it need accurate mapping and computer programes. Full cooperation between MWRI and that of the Ministry of Agriculture and land Reclamation (MALR) is of paramount importance.

- Modernization of irrigation systems should not only be restricted to upgrading or transformation of physical infrastructure but also the innovations or transformation in how irrigation systems are operated and managed i.e improved irrigation services.

- Conventional water-saving techniques have to be applied and, improved. These include precise land leveling, night irrigation, long furrows, modern irrigation in old lands, converting irrigation of orchards from gravity to pressurized systems (micro-irrigation) in old lands and introducing short duration varieties of crops etc.

- Performance improvement of large-scale schemes is necessary to promote water savings. These systems are facing technical, institutional, socio-economic, and governance problems. Modernization (infrastructure and services), participatory management and public-private-partnership are some of the possible measures to improve their performance. Successful institutional reforms require strong political backing and genuine interest in transferring responsibilities from government agencies to farmers associations.
- Virtual water (is the amount of water which is" imbedded" into or a product) trading offers solution in certain cases. Global water saving as a result of international trade of agricultural products has been estimated at about 350 billion m3/year. To maintain food security or food self-sufficiency, Egypt have over-exploited their renewable water resources. Trade can help mitigate water scarcity if the country can afford to import food from water-abundant countries. There is a strong need to develop a set of principles/rules governing virtual water trade.
- Maintaining a healthy relationship with African countries, in general, and Nile basin countries in particular, may lead to agreements enabling some of these countries to raise some crops, with the help of Egyptian expertise, under the favorite conditions of an ample water supply and open space.

Agriculture cropping pattern

- Rice is considered important crop in Egypt. The potential water savings in rice production is very large. The water saving techniques requires more control over the amount and timing of water applications than the traditional practices. Thus there is a need for further research to determine the additional infrastructural requirement and management skills in order to implement water saving irrigation practices.

- Crop pattern modifications should also be expanded to the south/north areas. Optimization should be in favor of drought tolerant crops being raised in the temperate south and salt tolerant crops in the north. This might cause a change in sugar cane/sugar beat cultivation. It might also concentrate winter vegetables in the south and summer vegetables in the north.

Winter oil producing crops are badly needed. Whether canola can be of use remains to be answered. Revolutionary ideas about changes in cropping patterns are a must

- Land consolidation in general or crop consolidation as a minimum, appears to be badly needed. Mixing crops on small areas of land results in the worst, conditions for each crop in those cases where crop water requirements and soil moisture conditions vary especially if a rotation irrigation system is applied to all crops.
- Bio-technology includes genetically modified crops can play an important role in reducing crop water requirements. Although there is a general consensus that bio-technology has a vital role to play in addressing the challenges of water scarcity, it has yet to show its full potential to deliver practical solutions to the farmers.

Farmers Participatory

- Farmers and field level staff area at the center of any process of change need to be encouraged and guided through appropriate technologies and practices towards water saving, conservation and farm level. Farmers often follow their traditional practices and have little no access to the new technologies and knowledge. Through extension services management information's to the farmers/field staff should be transferred on continuous basis.

- Strengthen the participation of the farming community by:
  - Allows farmers to identify soil, water and water management problems and concerns.
  - Mechanism allowing farmers to have input in water saving techniques.

- Irrigation institutions should be responsive to the needs of farmers, ensuring more reliable delivery of water, increasing transparencies in management and balancing efficiencies, timeliness and equity in conveyance, allocation and application of water. This calls for targeted investment infrastructure modernization, institutional restructuring, and upgrading of the technical and managerial capabilities of farmer and irrigation managers.

Water quality

- Non-conventional water resources i.e poor or marginal quality water (urban wastewater, agriculture drainage water, saline water and desalinated water) are not considered as renewable water resources but are an important source for irrigation. The poor duality water volumes are increasing. The challenge is to manage these flows properly, considering food safty, environmental issues, institutional arrangements and national and regional policies. Use of wastewater in peri-urban agriculture has become a reality in facing water scarcity. With the increase in urban population and increased demand for water for municipal and industrial uses, appropriate treatments of wastewater and its re-use for irrigation should be an important strategy to complement the fresh water resources.

9.3 The Challenges

- Development and adoption of water saving irrigation measures has improved our understanding and enriched our knowledge of water saving irrigation practices. However, one should endovor to save not only water, but also other farm inputs viz, energy, fertilizers and pesticides. Impact as downstream stakeholders should be kept in view while implementing water saving practices upstream of a catchment. Water saving irrigation practices should be environment friendly so as to ensure their sustainable adoption.

- With dramatically increasing population growth, agriculture has to accept leaving a part of its share of water for other activities. It is obliviously much better if such decisions are well planned a head of time.
- The challenge is how to incorporate innovative technologies and management approaches in decision making and long term management policy making. Exchange of ideas and communication among planner/decision makers, financial actors, scientists, local authorities,

establishing mechanism for cooperation and experience sharing among institutes for higher education and research and developing actor plans for concrete and practical follow-up are some of the possible options.

- In order to tackle this large number of conflicting objectives, it is necessary to use a multi-criteria decision support technique within or powerful tool, such as a decision support system (DSS). Such a system can handle the large number of parameters relevant to decision makers, the socio-economic life of the population and the technical system and enhance the logical thinking that policy and decision makers inevitably apply, as well as predicting the future using an integrated evaluation of alternative plans.

- There could perhaps be no single solution or a blue print for the future challenges in agricultural water management obviously. In the work presented here an attempt to highlight the scope offered by some of the innovations in respect of one or more aspects or water management has been made. The up scaling to achieve large water saving will depend on many factors.

9.4 Concluding Remarks

Those suggestions for sustainable development and adoption of water saving could be summarized in the following twelve proposals which can be translated into action plans for decision makers to adopt.

1. The potential savings in rice production is very large.
2. Matching irrigation supply and demand comes in the list of priorities as a major water savings measures.
3. Performance improvement of large-scale schemes is necessary to promote water saving of modernization infrastructure, participatory management, and public-private-partnership
4. Irrigation institutions should be responsive to the needs of farmers ensuring more reliable delivery of water, allocation and application of water.
5. Land consolidation or crop consolidation as a minimum, is badly needed.
6. Techniques and agricultural management requires urgent application
7. Crop pattern modifications-should be expanded. Drought tolerant crops and winter oil producing crops are also badly needed.

8. Bio-technology includes genetically modified crops play an important role in reducing crop water requirements.

9. Non-conventional water resources i.e poor quality water, (urban wastewater, agriculture drainage water, desalinated water) are required to be managed properly, considering environmental issues.

10. Water saving irrigation measures, however, one should endeavor to save not only water but also other farm inputs vis, energy, fertilizers and pesticides.

11. The challenge is how to incorporate innovative technologies and management in decision making process. There is a need to establish a mechanism for cooperation and experience sharing among different institutes.

12. To tackle these number of conflicting objectives, it is necessary to use a multi-criterion decision supper techniques (DSS).

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The present publication is a compilation of successful water saving innovative ideas and practices at the farm level and as a rich source of knowledge and reference work providing an inspiration of all professionals engaged in aspirating "more crop per drop"

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