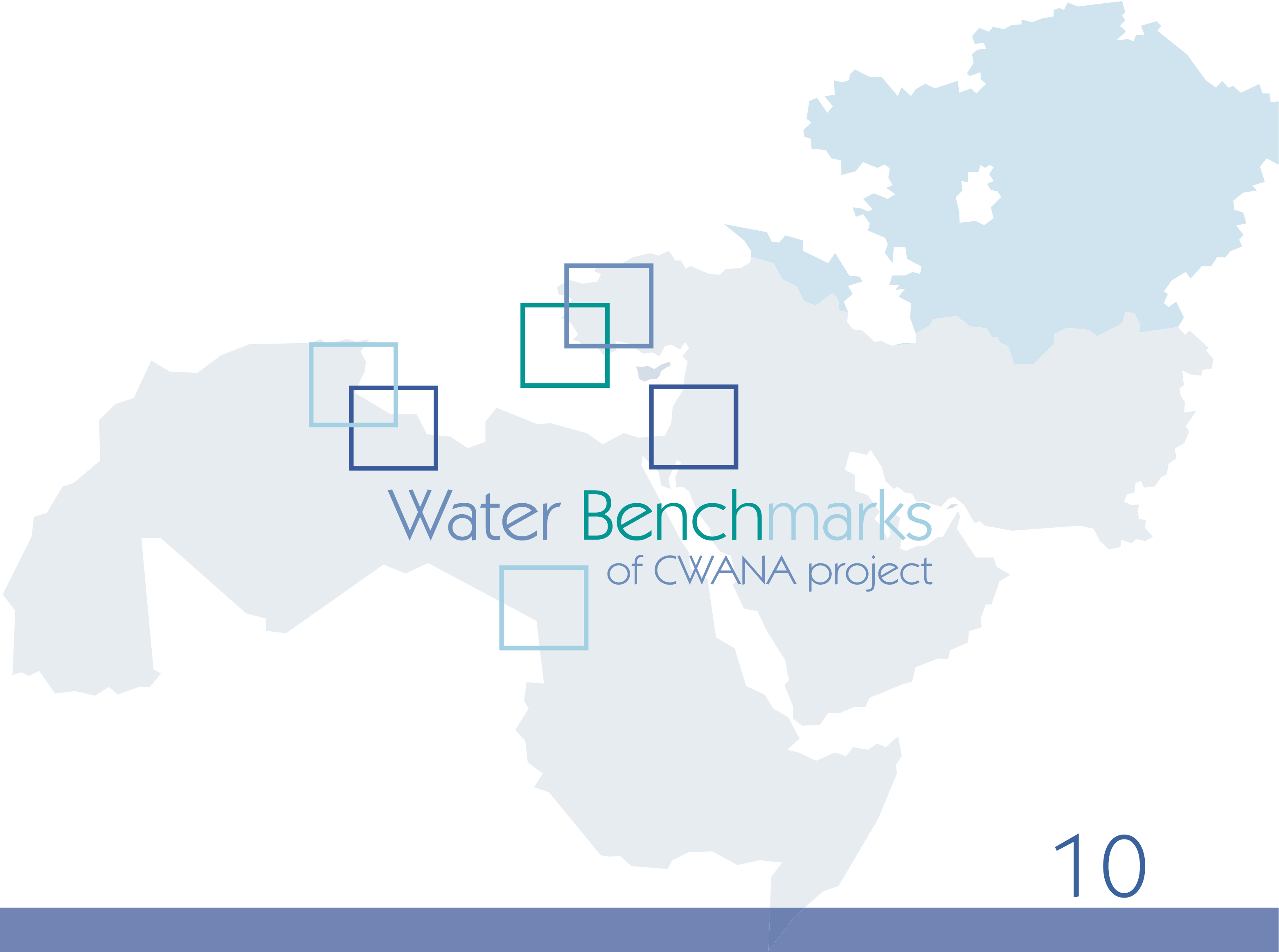

Water Benchmarks of CWANA project

10

Improving Water and Land Productivities in Irrigated Systems

Editors

M. Karrou, T. Oweis, B. Benli and A. Swelam

ICARDA
International Center
for Agricultural Research
in the Dry Areas

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Agricultural Research Center

Water Benchmarks of CWANA

Community-Based Optimization of the Management of Scarce Water Resources in Agriculture in CWANA

Improving Water and Land Productivities in Irrigated Systems

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EXECUTIVE SUMMARY

In Egypt, agriculture is receiving the lion's share of water, amounting to nearly 80% of the available water resources. The Egyptian policy is to fill the gap in food production, especially wheat, through vertical expansion of the irrigated areas and the horizontal expansion of new, reclaimed lands. Yearly, thousands upon thousands of hectares are reclaimed and added to the irrigated area; water will become the biggest limitation in the future. The prospect of water scarcity in all sectors in general, and agriculture in particular, will create very complex challenges for the irrigation sector. Because of this problem, more crops will have to be produced with less water in the agricultural sector. This requires very effective and serious action programs to reduce water losses and increase crop water productivity. Indeed, the more water saved, the greater the opportunity to expand the irrigated areas and increase food production, bringing the country towards food security.

Furthermore, through effective irrigation water management, fundamentally based on appropriate irrigation scheduling, soil salinity, alkalinity, and water logging problems due to over-irrigation can be avoided, thereby protecting the natural resources.

Technically, it is well recognized that improved water use efficiency offers a high potential for water saving. Therefore, in the irrigation sector, the broad message and the main objective must be to maximize the benefits of each drop of water applied. This necessitates identifying the exact water volumes and the right times for irrigation.

For cultivated crops, irrigation efficiency is achieved by applying the proper amounts of water at the right time to alleviate moisture stress during the most sensitive stages of crop growth. New technology can help in this process. But there is a wide technology gap between the required irrigation practices for essential major crops and the actual practices by farmers in most of the irrigated areas.

Both now and in the future, the major challenge is to explore the potential for the agricultural sector to conserve irrigated water at the farm and basin levels. Indeed, nowadays, saving water in irrigated areas is a top priority, technically and politically, to mitigate the looming water scarcity.

The overall objective of the project is to get farmers to maximize irrigation water productivity (WP) through the widespread integration and adoption of suitable irrigation practices in sustainable irrigated agricultural cropping systems.

This is the fundamental scope of the Irrigation Benchmark Project, where the emphasis was placed on introducing and implementing new water saving technologies. Additionally, emphasis was laid on the participation and involvement of farmers in water users' associations (WUA) and other community organizations, as well as with government organizations – particularly, those concerned in the Extension Service of the Ministry of Agriculture.

The implementation of the Irrigated Benchmark study to achieve the desired objective involved four main activities described below.

1. On-farm trials at selected locations to generate the data required for modeling WP and sustainability, and to fill the gaps in the available information necessary for improving water management.
2. Development of simulation models to assess water use efficiency and the environmental effects of different potential technologies in the different production systems under consideration.
3. Economic evaluation of the interventions tested.
4. Analysis of the existing policies and institutional setups regarding improving WP and the development of recommendations for improvement.

The project was conducted over a period of four years (2004-2008). The main findings of the project are summarized below.

- The results of the on-farm trials showed that the recommended irrigation techniques are simple practices that can be easily implemented by the farmers. They can lead to significant increases in the yield, crop water productivity, and water saving as compared with those the farmer is currently practicing.
- Deficit irrigation is a technique that showed a beneficial effect in maximizing crop water productivity. The results of the trials carried out in the selected sites (old lands, new lands, and marginal, salt-affected lands) showed that the implementation of such a technique, where a relatively high proportion of the water applied is saved, did not result in any significant losses in yield for the major crops.
- Raised bed technique (furrow technique) showed very satisfactory results in the different sites (old lands and marginal lands) investigated under cropping with the main winter crops (wheat and berseem) and the summer ones (corn and cotton). This technique, besides saving around 25% of the water applied, increased crop production by nearly 10% more than that produced following the farmer's customary irrigation practices. Furthermore, the implementation of such a simple technique resulted in an average water saving of between 20% and 25% over that corresponding to the basin irrigation practice of the farmers.
- In the old land sites, the trials conducted on wheat during the growing season 2006-2007 allowed verification of the validity of the hypothesis that we can produce the same yield, or more, by using less water. Irrigating wheat with a volume of water corresponding to just 70% of the crop water requirement showed that the yield was not significantly affected. Besides a notable improvement in the yield, the results showed that the average WP was 40% greater than that recorded under the conventional irrigation practiced by farmers.

In salt-affected soils, similar results were obtained. When the crop was irrigated with 70% of its water requirement, the reduction in wheat yield amounted to just 8% of that produced under full irrigation. This, again, confirms that we can produce nearly the same yield while saving up to 30% of the water traditionally used by the farmers.

The trials on wheat in the new lands, characterized by sandy soils, showed that with the application of 80% of the crop water requirement, the yield was not dramatically affected – the losses were only about 2% – but the crop water productivity was significantly increased (0.4 kg/m^3), being nearly 38% higher than that obtained following the usual practices of the farmers.

- **Berseem:** Berseem is the second major winter crop. The research findings from trials conducted in the old lands indicated that such a crop could be successfully grown under a deficit irrigation technique because it responded like the wheat crop. For this crop, deficit irrigation reduced the seasonal water applied by the farmer by nearly 44% with a reduction in yield over that obtained by using fresh water not exceeding 12%. This represented an increase in water productivity of 33% over that obtained by the farmers' irrigation practices.
- **Corn:** In the old lands, when corn was irrigated with 75% of the crop requirement the average losses in the yield in two cropping seasons was between 4% and 12% as compared to the conventional irrigation practices. This high water saving without significant yield reduction under deficit irrigation resulted in increasing the crop water productivity by nearly 20%.
- **Cotton:** In the old lands, the data clearly indicated that the cotton yield could

be produced successfully under deficit irrigation. Using 75% of the full water requirement of the crop resulted in a yield reduction of just 10%. This was also the case for the experimental trial conducted in the marginal lands.

- **Rice:** Trials on rice under different irrigation intervals were conducted in the marginal lands. The research findings for the two successive irrigation seasons, 2006 and 2007, can be summarized as follows:
  - Irrigation at four days intervals with a water depth of 7 cm resulted in a 9% water saving and an increase in rice yield of nearly 7% compared to that obtained by the farmer's practices;
  - Increasing the irrigation interval from four days to eight days with the same water depth increased the amount of water saved by nearly 22%, showing a yield more or less similar to that under the farmers' irrigation practices – just a 2% yield loss;
  - Saturating the soil with irrigation water appeared to be the practice which lead to the highest water saving (around 44%); but the yield was reduced by nearly 16% as compared with that obtained under the farmers' irrigation practices.
- A comparative analysis of the measured and predicted yield data under varying degrees of water stress for the crops under investigation showed that the yield stress model can adequately predict the yield reduction resulting from imposed water stress. The use of the model can provide useful insights into the design of different irrigation treatments. The ease with which the model can be used and run could help in the wider use of deficit irrigation techniques, thereby achieving greater water savings in the agricultural sector. The results of the model validation under full irrigation and deficit irrigation clearly confirm that the model is appropriate for predicting the yield and investigating the degree of crop tolerance to water stress. Furthermore, the results also suggested that the model can be used in irrigation scheduling to conserve irrigation water with almost insignificant yield reductions.
- The enterprise, partial budget, and economic analyses indicated the superiority of the new irrigation options in increasing net unit water returns, reducing costs, and water savings as well as a potential to increase farm income, livelihood, and alleviating poverty. Specifically, the raised bed option was best suited for wheat and faba bean in winter and maize in summer. It was also found that the soil saturation option had a potential for rice in the marginal lands of El-Serw. The deficit irrigation technique was found to be the second choice for winter crops, especially, wheat. However, productivity might decrease under the saturation and deficit options.
- Partial budget analysis of the result of scaling-out activities throughout the governorates showed that wide furrow and raised bed always have a higher benefit to cost (B/C) ratio, For the raised bed option, the average increase in the net benefits was 40% while the B/C ratio increased by 20% in all governorates studied. Additionally, using raised beds reduced variable costs by 30%, on average. Scaling-out analysis showed that wide furrow was a more profitable option which was widely accepted and adopted by communities in the project areas and the neighboring governorates.
- Existing water policies and institutional set-ups in Egypt were analyzed and constraints and potential improvement aspects were identified. Listed below are the constraints faced by the existing water organizations in Egypt, together with suggestions for improving their role and the implications for water management.
  - The state has not yet decided on the optimum level of user participation

regarding the mesqa (tertiary canals), the collector drain, the branch canal, the main canal, or the irrigation district.

- Both parties, the users and the state, are still reluctant to move on the basis of the experience from pilot to policy. For the government, the possibility of implementing failing experiments may be the reason for this reluctance, while for the users the need for an external and neutral arbitrator may be the reason.
- The ability of registered associations to collect money for different purposes, to impose penalties, or to offer incentives to members or outsiders is not yet decided.
- The issue of service providers is crucial. Retired irrigation engineers and former employees of the Ministry of Agriculture provide an excellent advisory membership to water users' associations (WUAs).
- The coordination between WUAs and government agencies, extension services, irrigation advisory services, and cooperatives is not well established and identified.
- WUAs have the right to takeover a facility (mesqa, control structures, etc.) which is in perfect condition. They also have the right to obtain funds which can be allocated for operation and maintenance and spent by the state.
- For independent WUAs, the ability to utilize surplus money for investment in activities that benefit the members (with their full agreement) should be guaranteed. Such benefits include pumping water to non-members, selling services (e.g., repair of pumps), changing irrigation systems (modernizing), selling pipes, etc.
- It might be better if the transfer of management starts with joint management between users and government agencies. When the latter feel that the users are capable, the government agencies may start to withdraw.

Background

Water scarcity in West Asia and North Africa (WANA) is a well-known and alarming problem. Today the issue is of increasing concern to national governments and research institutions. Increasing water scarcity is threatening the economic development and the stability of many parts of the region. At present, agriculture accounts for over 75% of the total consumption of water. However, with the rapidly growing demand it seems certain that water will increasingly be reallocated away from agriculture to other sectors. Moreover, opportunities for the significant capture of new water are now limited. Most river systems that were suitable for large-scale irrigation have already been developed. Few major resources of renewable groundwater remain untapped and current resources are subject to overexploitation, with extraction exceeding the recharge rate in many cases.

While gains in efficiency are potentially available from improved distribution and use of water in fully irrigated agriculture, a great proportion of the region's agricultural livelihoods are based on dryland farming systems where production is dependent on low and extremely variable rainfall. The challenge in rainfed areas is to enhance productivity by improving on-farm water use efficiency and supplementing rainfall either through water harvesting or the strategic use of sources of renewable water to augment essentially rainfed production. However, conventional practices, which have been developed for managing water under normal water supply conditions, are not suitable under conditions of water scarcity. The need for the special management of water under conditions of scarcity, based on maximizing the return from each unit of water available for agriculture, now applies to almost all the countries of WANA.

Technologies for the improved management of scarce water resources are available. However, many of these technologies are not widely implemented or seen as feasible by farmers. This can be attributed to a number of constraints, including technical, socioeconomic, and policy factors, but, most importantly, the lack of community participation in the development and implementation of improved technologies. This project is based on community participation in the research and development, testing, and adaptation of improved water management options at the farm level. The project consisted of three main components; the Badia Benchmark site in Jordan, with two satellite sites in Saudi Arabia and Libya, the Rainfed Benchmark site in Morocco, with three satellite sites in Tunisia, Algeria and Syria, and the Irrigated Benchmark site in Egypt, with two satellite sites in Sudan and Iraq.

Objectives and outputs

The main long-term development goals of the project are to achieve sustainable and profitable agricultural production in the dry areas of WANA based upon the efficient and sustainable management of the scarce water resources.

To achieve these goals the project developed and tested, with community participation, water management options that increase water productivity and optimize water use, and which are economically viable, socially acceptable, and environmentally sound.

The research concentrated its activities in the three benchmark sites. Each benchmark site was linked to satellite sites as indicated earlier. These satellite sites were designated to complement the research of the benchmark.

The four main expected outputs of the project are:

- Strategies and tested technologies for the optimal conjunctive use of rainwater and scarce water resources in supplemental irrigation systems adopted by farming communities for improved and sustainable water productivity in the rainfed areas on WANA

- Suitable water harvesting techniques to capture and efficiently utilize rainwater runoff in more productive and sustainable agricultural systems, integrated and adopted by people in the drier environments of the WANA.
- Techniques and systems that optimize water productivity in irrigated systems, including water management, alternative crops, use of different water sources, and policy and institutional options.
- Enhanced capabilities of national programs and the integration of researchers, extension personnel, farmers, and decision makers in a regional program for the sustainable management of water resources.

The project approach

The project approach is based on five principles – participation, integration, complementarities, multidisciplinary and multi-institutions, and socioeconomic analysis.

a) Community, participatory based approach

The project uses an integrated approach, based on community participation. At each site, the local community is a full partner in the planning, implementation, monitoring, and evaluation. Farmers work with scientists and extension staff to test a range of 'best-bet' technologies and select those that best meet their needs – often adapting the technologies to suit local conditions. This creates a sense of 'ownership', leading to rapid adoption of technologies that were found to be effective and relevant.

b) Integrating technologies with policy and institutions

The project addressed the problems from technical, socioeconomic, cultural, institutional, and policy perspectives, with the full participation of the intended beneficiaries and other stakeholders.

c) Benchmark and satellites sites (complementarities)

Benchmark sites were established in the three agro-ecologies (rainfed areas, the steppe, and irrigated areas) to study these issues. At these benchmark sites, water use as addressed at different levels – the household, community, watershed, and, policy levels. Each of these benchmark sites were linked to several satellite sites as indicated in the previous section.

The benchmark sites represent the majority of the conditions in the above three agro-ecologies. However, some conditions and issues in the region related to the natural resources, the environment, and/or the socioeconomics may not be apparent in the benchmark site and thus are addressed in the satellite sites. Examples include water quality, special soil conditions, and local water-related policies and institutions.

d) Multidisciplinary, multi-institutions

The project approach requires multidisciplinary and inter-institutional teams, involving many different research disciplines, to understand the current situation and to develop and test water-use efficient technologies under farm conditions.

e) Socioeconomic analysis and community participation

Socioeconomic surveys that characterize the communities involved in the project sites were conducted to identify the main technical, social, economic, and environmental problems that constrain community livelihood improvement. The surveys also focused on the water resources available at the community level and how people deal with these. The surveys' results established the baseline information for the project target areas and communities. Following that, the communities participated in the development of the work plans and the intended interventions that the project would introduce. A community action plan was developed and implemented by the project with full community participation.

A community-based participatory monitoring and evaluation (PME) system was developed in the first phase. The PME involves local people in deciding how progress should be measured, in defining criteria for success, and in determining how results should be acted upon. It will strive to be an internal learning process that enables local people to reflect on past experience, examine present realities, revisit objectives, and define future strategies by recognizing different stakeholders' priorities and negotiating their diverse claims and interests.

Technical and socioeconomic indicators of progress and impact were developed during the commencement workshop and were implemented by the project teams. Major indicators include the level of adoption by communities of the technologies introduced.

Agriculture in Egypt relies heavily on irrigation water from the Nile. Compared to a century ago, the annual per capita share of fresh water resources has declined by more than 80% and could fall again by more than one-half in the first quarter of this century. The land itself is in short supply due to population over-growth. The cultivated area per person, 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 agricultural 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's 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 large-scale irrigation have been developed already. Few major resources of renewable groundwater remain untapped and current resources are subject to overexploitation, with extraction exceeding the recharge rate in many cases.

Fully irrigated areas in WANA are associated with the permanent availability of surface water, such as rivers, and of renewable groundwater resources. These irrigated areas provide most of the food in this region because irrigation permits more intensive agriculture. Recently, the demands of expanding populations have increased the pressure to raise production from these systems, threatening their sustainability. Marginal quality water is being widely used without proper management causing salinity and deterioration of the environment.

The irrigated areas will continue to be vital for food security in the region. To meet increasing demands for food, many countries in the region, such as Egypt and Syria, are 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.

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, varieties, and agronomic management?
- What water management guidelines are needed under conditions of water scarcity to produce more with less water?
- How does the farmer select his/her cropping patterns and inputs to maximize income as well as water productivity? Can this be developed into a general decision support tool?
- 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 production and livelihoods?

- How can the production systems be sustainable under increasing risk of salinization and land degradation?
- How can farmers manage water more efficiently and what policy options/ incentives are needed?
- What are the policies needed to encourage efficient water use in irrigated areas?
- How can marginal-quality water be used for high productivity without degrading the land?

Irrigated benchmark site in Egypt with satellite sites in Sudan

The Nile Valley is a typical and, maybe, the largest irrigated area in the region. Egypt is expanding its irrigated areas while water resources are not increasing. Sustainability is being threatened by excessive pressure and changing land use. Low quality water is being used without treatment which results in soil deterioration in the long-term.

The results from national research institutes in Egypt show the urgent need to develop approaches to improve water productivity and protect ecosystems from the threat of increasing salinity and land degradation. These problems define a common research task – to develop and integrate techniques and technologies with full community participation for the acquisition and supply of water to agriculture and for the efficient use of all sources of water in irrigated agricultural production. In this project, a benchmark site in Egypt was chosen to be representative of irrigated areas in the region with research results that should be transferable to other irrigated areas of WANA. The two other major irrigated countries of the region are Sudan and Iraq. Two satellite sites were established in these countries.

The main objectives of this study are the widespread integration and adoption by farmers using irrigated agriculture, of suitable irrigation systems and methods to maximize irrigation water productivity in more productive and sustainable irrigated agricultural cropping systems. The study was conducted in the old, new and marginal lands of the Nile Delta.

Chapter 1: Towards sustainable and improved water productivity in the old lands of the Nile Delta

Chapter 1: Towards sustainable and improved water productivity in the old lands of the Nile Delta

R. Abo El-Enein, M. Sherif, M. Karrou, T. Oweis, B. Benli and H. Farahani

1.1 Characteristics of the old land

The selected site, El-Makata, is located in east Menoufia Governorate in the Middle Delta, beside the Alatf canal to the west of the Damietta branch of the Nile. It is about 10 km east of Alexandria by desert road and 12 km from Shebin Al Koum city, as shown in Figure 1.1.

The selected site, has the typical characteristics of the old lands – an intensive cropping pattern (two or three crops a year), surface irrigation systems are prevalent, both traditional and improved irrigation systems exist, there are the severe drainage problems associated with a high water table, and land fragmentation. After agricultural liberalization, cropping patterns gradually changed with an expansion of vegetable production at the expense of field crops.

Alatf secondary canal, which retains both an open canal and closed pipe irrigation systems, was selected as the source of water. The canal begins at Al Bagour District in Menoufia and ends at Zefta District in Gharbia. It is about 4.8 km long and serves more than 11,000 ha.

Almakatei village, located on Alatf canal, was selected purposely to represent the community. Its agricultural land is located across three main districts in Menoufia Governorate – Al Bagour, Shebin Al Koum and Quesna. This was considered as one of the main advantages of selecting this site. El-Menira tertiary on Alatf canal was selected as the site for the study of the pipeline group. It is about 870 m long and it serves an area of about 40 ha. El-Hamra tertiary was selected for the study of the open canal group and serves an area of 30 ha.

Figure 1.1 The old lands site location at El-Makata, Menoufia Governorate.

The climate of the selected site is typical of the Nile delta, it is quite cold and dry in winter with very little rain and it is very humid, dry, and hot in summer. The khammaseen sand storms are common in March and April.

The soil of the old lands (Table 1.1) is clayey with a clay content of between 31% and 43%. The electrical conductivity (EC) value is, on average, 0.43 dS/m indicating the absence of any salinity problems; the soils were alkaline with an average pH value around 8.0. The selected site, has the typical characteristics of the old lands – an intensive cropping pattern (two or three crops a year), surface irrigation systems are prevalent, both traditional and improved irrigation systems exist, there are the severe drainage problems associated with a high water table, and land fragmentation. After agricultural liberalization, cropping patterns gradually changed with an expansion of vegetable production at the expense of field crops.

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1.1.1 Soil and soil nutrient improvement practices

The two groups apply their own manure and chemical fertilizers on their crops. Farmers use urea (46%), ammonium sulfate (33%), and superphosphate (15.5%) as chemical fertilizers as illustrated in Table 1.2.

Table 1.1. Fertility and physical and chemical analyses of the soils of the old lands (El Monofia).

	Soil fertility analysis			Physical and chemical analysis					
Farm	**N (ppm)**	**P (ppm)**	**K (ppm)**	**Coarse sand (%)**	**Fine sand (%)**	**Silt (%)**	**Clay (%)**	**pH (1:2.5)**	**EC (dS/m)**
Pipeline									
1	100	23.92	430	8.26	19.11	32.10	40.53	8.09	0.51
2	95	16.90	420	7.03	16.95	32.96	43.26	8.24	0.41
Open Canal									
3	75	13.26	390	4.73	26.75	37.41	31.11	7.99	0.44
4	125	17.42	230	5.89	23.63	29.48	41.00	7.92	0.36

Table 1.2. Quantities of fertilizer applied at the two sites.

Item	Pipeline	Open canal
Manure		
Availability	Yes	Yes
Application	Yes	Yes
Quantity (m^3/feddan)	30	70
EGP/m^3	5	5
Leaf fertilizer		
Application	No	No
Chemical fertilizer (50 kg bag)		
Urea 46.5%	6	6
Ammonium sulfate 20%	6	4
Mono Superphosphate 15.5%	1	1
Potassium 48%	6	6

Note: EGP – Egyptian pound
1 feddan is 4200 m^2.

1.1.2 Crop varieties

The varieties planted by the two groups were wheat varieties Sakha 93 and Sakha 68, maize varieties Hybrid 10 and Bashayer hybrid, and potato varieties Sponta, Kara, and Nikola.

1.1.3 Water management and supply

There is a significant difference in the water supply between the pipeline and open canal sites. Water is available daily at El-Menira (pipeline). For the open canal site (at El-Hamra mesqa), water is available for one or two days.

The water supply also varies among farmers at both the head and tail of the El-Hamra pipeline. In general, the supply of water is not really a criterion for differentiation between farmers in El-Menira, rather it is the cropping patterns and rotations they practice. Generally, farmers suffer from water shortages during the summer season in the open canal sites. The main irrigation sources in the area are the Nile River, Alatf canal, and groundwater wells.

1.1.4 Pest and weeds control

Weed infestation is a problem in the fields of both sites. Manure and water are

Table 1.3. Soil improvement practices for the two sites.

Group	Category	Proportion of farmers (%)
Improved mesqa (El-Menira site)	* Sub soiling	62.5
	* Manure	100
	* Legume	87.5
	* Sub soiling + manure	6.7
	* Manure + legume	40.0
	* Sub soiling + manure + legume	46.7
	* None	0.0
Unimproved mesqa (El-Hamra site)	* Sub soiling	26.7
	* Manure	93.3
	* Legume	93.3
	* Sub soiling + manure	6.7
	* Manure + legume	73.3
	* Sub soiling + manure + legume	13.3
	* None	6.7

the main reasons for this infestation. The pipeline site applies herbicides, while the open canal site resorts to manual weed control. Aphids and cotton leaf worm are the main plant pests and farmers use manual methods and apply chemical pest controls at the two sites.

1.1.5 Socioeconomic characteristics of the community

The majority of the farms are small in size (between 0.5 and 2 ha), and the farm area is divided into small pieces. Table 1.4 summarizes the farm groups and their distribution.

Most farmers have large families (human consumption unit – HCU). The average land area available per family member (cultivated area by human consumption unit – CA/HCU) at the El-Menira site is estimated at 0.1 ha/HCU while that at the El-Hamra site is 0.18 ha/HCU. The average human labor unit (HLU) available per hectare is less (1.0 HLU/ha) at the EL-Hamra site than that at the El-Menira site (1.07 HLU/ha). Therefore, the need for hired labor is greater at the EL-Hamra site.

Seventy five percent of farmers have animals; the others usually have a small cultivated area, do another job, or are not interested in livestock production. The average livestock unit (LU) ranges between 1.51 and 1.56. Buffalo is the dominant livestock at the sites as shown in Table 1.5. Table 1.6 summarizes the farmers' incomes through agriculture.

Table 1.4. Farm sizes at the two sites.

Group	Farm size (ha)	Frequency	%
Pipeline site (El-Menira site)	>1	1	20
	1-3	4	80
Total		5	100
Open canal site (El-Hamra site)	>1	3	60
	1-3	2	40
Total		5	100

1.1.6 Cropping patterns

Table 1.7 presents the most common cropping patterns at the selected sites. It was observed that maize is the main crop in summer while in winter wheat and berseem are the main crops at the two sites.

The main crop rotations for the two sites include wheat and berseem in the winter and maize and sweet potatoes during the summer.

Table 1.5. Livestock units (LU) at the two sites.

Group	Description	Cows	Buffaloes	Sheep	Goats	Donkeys	Total
El-Menira site	Big animal	0.53	0.57	0.08	0.11	0.18	1.54
	Small animal	0.15	0.14	0.01	0.01	0.01	0.32
	Total animals	0.65	0.68	0.08	0.12	0.17	1.63
	Total LU	0.65	0.79	0.02	0.02	0.08	1.56
El-Hamra site	Big animal	0.35	0.73	0.10	0.15	0.24	1.57
	Small animal	0.06	0.10	0.00	0.01	0.03	0.14
	Total animals	0.46	0.79	0.10	0.16	0.28	1.78
	Total LU	0.39	0.96	0.02	0.03	0.11	1.51

Table 1.6. Income earned from different farm activities for the two sites.

Group	Income component	Average proportion of total farm income (%)	Minimum (%)	Maximum (%)
El-Menira	Field crops	35.6	15	70
	Horticulture and vegetable	31.6	20	100
	Livestock	32.8	10	50
El-Hamra	Field crops	32.1	20	50
	Horticulture and vegetable	35.4	20	70
	Livestock	32.5	20	50

Source: Collected and calculated from the multidisciplinary survey.

Table 1.7. Cropping patterns at the two sites.

Group	Summer 2006	Winter
Pipeline	Maize, cotton, potatoes, sweet potatoes	Wheat, berseem, sweet potatoes
Open canal	Maize, cabbage	Wheat, berseem

1.1.7 Cultivated area

Table 1.8 presents the cultivated areas by crop type at the two sites in winter and summer.

1.1.8 Crop profitability

Table 1.9 shows the crop budget for the two groups. It shows that the profitability of the wheat crop ranged between 493% and 796% for the pipeline site, compared to a range of 346% to 531% for the open canal site. Berseem profitability was about 642% for the pipeline site compared to a range of between 459% and 721% for the open canal site.

1.1.9 Land productivity

The productivity of the lands of the two sites is almost the same, except during the summer and for sweet potatoes. The productivity of summer potatoes in El-Menira is higher than it is in the El-Hamra. However, the productivity of sweet potatoes in El-Hamra is higher (see Table 1.10).

1.2 Objectives and methodologies

A lot of research work has been undertaken and appropriate technologies have been developed. Nevertheless, water losses and degradation remain high at the farm level. Unfortunately, it is the transfer of knowledge to the farmers in the field that is lacking. To overcome this challenge, community based practices are essential.

The main objectives of the work conducted in the three project sites (old, new and marginal lands) were as follows;

- On-farm improvement in water management to reduce water losses and ensure better water saving;
- Introduction, with the involvement and partnership of farmers, of new, simple, accepted techniques to increase crop water productivity without negative impacts on yield;
- Test and dissemination of new water interventions and ensure their dissemination in the target communities.

Table 1.8. Cultivated area by crop type by season at the two sites.

Group	Code No.	Winter 2004-2005		Summer 2005		Winter 2005-2006		Summer 2006	
		Crop	Area (ha)	Crop	Area (ha)	Crop	Area (ha)	Crop	Area (ha)
El-Menira site	1	Berseem, wheat	0.20	Maize	0.40	Wheat	0.40	Maize	0.20
	2	Wheat	0.20	Cotton Maize	0.13	Wheat, berseem	0.40	Maize	0.53
	3	Wheat	0.40	Sweet potato	0.26	Wheat	0.40	Maize	0.00
	4	Wheat	0.40	Maize sweet potato	0.40	Wheat	0.40	Maize	0.60
	5	Wheat	0.40	Maize	0.20	Berseem	0.40	Sweet potato	0.20
El-Hamra site	1	Wheat	0.13	Tomato	0.20	Wheat	0.13	Maize	0.00
	2	Berseem	0.40	Maize	0.13	Berseem	0.20	Maize	0.13
	3	Wheat	0.40	Maize	0.17	Wheat, berseem	0.20	Maize	0.40
	4	Wheat, potato	0.17	Maize	0.23	Wheat, berseem	0.40	Maize	0.40
	5	Wheat	0.40	Maize	0.17	Berseem, potato	0.10	Maize	0.13

Surface irrigation is the most common system for about 80% of the irrigated area in Egypt. Generally it has a lower application efficiency than other methods because of the high water losses and the inefficient method of application. An optimal irrigation application throughout the growing season is important for increasing water productivity without additional costs.

In this project a new surface irrigation strategy to improve water productivity, called raised bed, was introduced to the farmers. The traditional method for wheat and berseem planting in Egypt is random broadcasting of the seed or using a seed-drill machine on flat land. The field is divided into borders in order to control the irrigation water. The typical, traditional farming practice for wheat irrigation is to apply water onto the borders in sequence from the top to the bottom of the field. The irrigation water has to pass through the whole border with the application stopping when water approaches the end of the border.

In the raised bed system, wheat and berseem seeds are planted over the ridges with the same plant density as in the traditional methods as shown in Figures 1.2 and 1.3. During irrigation, water is applied in the bottom of the furrows and this reduces the irrigation time and amount of irrigation water. The wetted area is less than in the traditional methods hence the irrigation cost is reduced.

Table 1.9. Crop profitability.

Group	Code No.	Winter 2004-2005			Summer 2005			Winter 2005-2006			Summer 2006		
		Crop	TR	V. cost	Crop	TR	V. cost	Crop	TR	V. cost	Crop	TR	V. cost
El-Menira site	1	Berseem	1400	254.4	Maize	1032	360.4	Wheat	1452	237.2	Maize	824	376
		Wheat	1968	264									
	2	Berseem	396	104	Cotton	1430	226.8	Wheat	1736	292.4	Maize	923.2	399.2
		Wheat	1246	272	Maize	722.8	264	Berseem	1836	246.8			
	3	Wheat	1944	248.4	Sweet potato	2440	468	Wheat	2144	239.2	Maize	880	456
											Green bean	1040	209.2
	4	Wheat	1940	171.2	Maize	960	384	Wheat	1792	277.2	Maize	640	355.6
					Sweet potato	1945.6	317.6						
	5	Wheat	1648	218.8	Maize	960	495.6	Berseem	1508	172	Sweet potato	1212	503.2
El-Hamra site	1	Wheat	1640	159.2	Tomato	4762	404.8	Wheat	1456	273.6	Maize	640	302.4
		Berseem	1800	322				Berseem	1620	209.6			
	2	Berseem	1428.4	171.6	Maize	1428.4	251.6	Berseem	1620	290	Maize	856	382
	3	Wheat	1600	202.4	Maize	1152	431.2	Wheat	1584	251.2	Maize	824.4	514
								Berseem	1515.2	249.2			
	4	Wheat	1248.4	86.4	Maize	1152	395	Wheat	1400	313.6	Maize	666.8	344.8
		Potato	1600	1609.6				Berseem	1620	232			
	5	Wheat	1773.2	277.2	Maize	1381.2	405.6	Berseem	1872	228	Maize	888	414.4
								Potato	2080	668.8			

Note: TR – total revenue (EGP/ha); V. cost – variable costs (EGP/ha).

Table 1.10. Productivity of the main crops at the two sites.

Crop	Pipeline site (El-Menira) (t/ha)	Open canal site (El-Hamra) (t/ha)
Winter crops:		
Wheat	3.1	3.1
Potatoes		8.0
Berseem	15.0	15.0
Summer season:		
Tomatoes	20.0	
Cotton	1.1	
Maize	2.8	2.8
Summer potatoes	20.0	12.0
Taro	18.0	18.0
Sweet potatoes	12.0	20.0

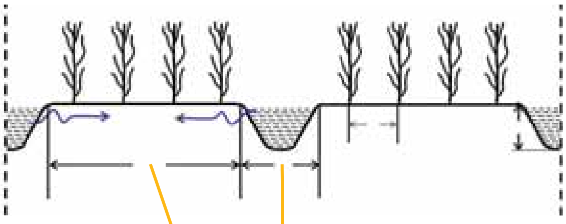

Figure 1.2. Schematic diagram of the raised bed method of wheat production.

Figure 1.3 Photograph of the raised bed method of wheat production.

The method has a better performance as there is less need to apply water to all the 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 fertilizer, and easier weed control and other agricultural practices.

The traditional method for maize and cotton planting is in rows 0.65 m apart with one row of plants on each ridge between furrows and 0.22 m between plants within the rows. The furrows are about 0.20 m deep and the ends of the furrows are blocked to prevent runoff from the field. When water is applied in the traditional method the application stops when the water level in the furrows approaches the top of the furrow ridge. Figure 1.4 illustrates a typical farming practice.

The raised bed, wide furrow system decreases the irrigated area and reduces the amount of water required to fill the furrows to the ridges of the borders. In this method the furrow spacing was duplicated (two furrows were merged). This is double that of the traditional method, but there are two rows of maize or cotton planted on a ridge as shown in Figures 1.5 and 1.6, so the plant density remains the same as in the traditional method. Because the number of furrows in the recommended method is half that in the traditional method, considerably less water was applied for the same plant density. This method increased water saving as compared to the traditional method.

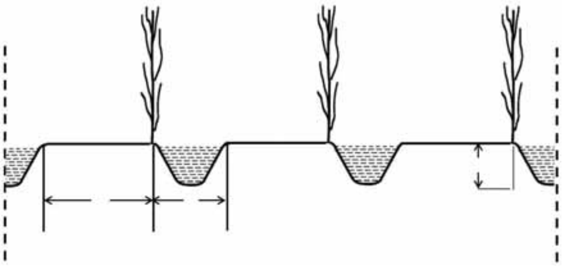

Figure 1.4. Schematic diagram of the traditional furrow method.

Figure 1.5. Photograph of mature maize planted using the wide furrow method.

Figure 1.6. Photograph of cotton planted using the wide furrow method.

It is hypothesized that this method has better performance because less water is applied, which leads to a decrease in percolation losses. In addition, shading of the wetted soil in the furrows by the plants is also likely to decrease evaporation. Since the irrigation requirement is reduced, the costs for pumping and labor are reduced. The use of this method insured good aeration of the roots, high use of solar radiation, efficient use of fertilizers, and was easier for weed control and other agricultural practices. All these factors affect the yield. Using this method resulted in a yield increase.

The following treatments were applied in both the winter and summer seasons to the old lands project site:

1.2.1 Winter crops

Wheat

- Traditional irrigation practices, narrow furrows, and planting in hills
- Full irrigation (evapotranspiration (ET) + 0.2ET for leaching), narrow furrows
- 70% of full irrigation, narrow furrows hills
- Wide furrow planting in hills or W.Fh (for areas of less than half hectare)
- Wide furrow after broadcasting or WFb (larger areas)
- Basin irrigation + broadcasting

Berseem (dry and wet planting):

- Traditional irrigation practices, basin irrigation.
- Full irrigation (ET+0.2 ET for leaching requirements), basin irrigation.
- 70% of full irrigation, basin irrigation.

1.2.2 Summer crops

Cotton

- Full irrigation (1.2 ET).
- Deficit irrigation (70% of full irrigation)
- Farmers' irrigation practices
- Wide furrow irrigation (combining two furrows)

Maize

- Full irrigation (1.2 ET)
- Deficit irrigation (070% of full irrigation)
- Farmers' irrigation practices
- Wide furrow irrigation (combining two furrows)

1.3 Results

1.3.1 Wheat

Deficit irrigation (70% of full irrigation) saved from 105 mm to 127 mm of water as compared to the farmers' practices (narrow furrows). This was from 20% to 28%

less than what was used by the farmers in 2005-2006.The values in 2006-2007 were from 120 mm to 209 mm less than the amount of water normally applied by the farmers – between 26% and 32% less – as shown in Table 1.11, the averages were 171 mm (23%) for the first season and 172 mm (29%) for the second.

The effect of deficit irrigation on the yield of wheat is shown in Tables 1.11 and 1.12. Generally, no significant difference was found between the yield under deficit irrigation and that achieved following the farmer's irrigation practices. This non-significant reduction recorded at Farm 3 was 1004 kg/ha (17%) in the 2005-2006 season and 453 kg/ha (7%) for the 2006-2007 season. However, the savings in the amount of water applied were 23% and 26%.

For Farms 1, 2, and 4, deficit irrigation in 2005-2006 gave the same yield, 2.8% less yield and 11% higher yield, respectively, as compared to the farmers' traditional practices. In the 2006-2007 season on Farms 1, 2, 4, and 5, deficit irrigation mostly resulted in non-significant increases in yields –175 kg/ha (3%), 36 kg/ha (1%), 722 kg/ha (12%) and 13 kg/ha, (2%) – as compared to the farmers' standard irrigation practices.

The data indicated that, in general, farmers did not use a clear excess of irrigation water as compared with the water required. The seasonal irrigation water requirement ranged from 503.1 mm to 556 mm in the first season and from 390 mm to 590mm in the second, while that applied by the farmers' practices was between 511 mm and 557mm and 433 mm and 675mm in these periods. The average over all farms showed that the amounts of water applied following the farmers' practices was 536.9 mm (first season) and 582 mm (second season) against the full irrigation water requirements of 534.13 mm and 521 mm.

For all the farms, irrigation with 70% of the full requirement resulted in saving more than 115 mm and 113 mm – representing a saving of about 21% – (see Table 1.11) on the farmers' practices and full irrigation, respectively.

Average grain yields of 8.56 t/ha, 8.33 t/ha, and 8.44 t/ha and water productivities of 1.60 kg/m^3, 1.56 kg/m^3, and 2.00 kg/m^3 were obtained by the farmers' practices, full irrigation, and 70% of full irrigation, respectively for the first season. For the second season, full irrigation and deficit irrigation increased grain yields by 375 kg/ha and 36 kg/ha and improved water productivities by 0.196 kg/m^3 and 0.491 kg/m^3, respectively as compared to the farmers' practices.

Table 1.11. Effect of interventions on the amount of water applied for growing wheat in old land sites.

Farm	Amount water applied 2005-2006 (mm)				Amount water applied 2006-2007 (mm)					
	Farmer	Req	0.7 req	RB$_h$	Farmer	Req	0.7 req	RB$_h$	RB$_b$	Basin
1	540	556	436	400	675	595	466	490	493	695
2	557	550	430	416	633	562	443	478	479	
3	511	503	396	344	608	570	449	487	490	
4	540	527	420	376	560	487	379	424	429	
5					433	390	313	346	358	533
Aver	536.9	534.1	420.5	384.1	582	521	410	445	450	614

Note: RB$_h$ – raised bed hills; RB$_b$ – raised bed broadcasting.

Table 1.12. Effects of interventions on wheat yields in old land sites.

Farm	Wheat yield 2005-2006 (t/ha)				Wheat yield 2006-2007 (t/ha)					
	Farmer	Req	0.7 req	RB_h	Farmer	Req	0.7 req	RB_h	RB_b	Basin
1	9.429	9.321	9.464	8.964	6.064^{a}	6.399^{ab}	6.239^{ab}	6.472^{ab}	6.668^{b}	5.95^{a}
2	7.607^{b}	8.321^{ab}	7.393	8.607^{a}	6.074	6.449	6.11	6.34	6.614	NS
3	7.75	7.679	6.646	8.393	6.373^{ab}	6.415^{ab}	5.92^{a}	6.442^{ab}	6.55^{b}	
4	9.44	8	10.44	10	6.148^{a}	7.07^{b}	6.87^{b}	7.003^{b}	7.166^{b}	
5					6.4^{b}	6.47^{b}	6.53^{b}	6.54^{b}	7.71^{c}	4.67^{a}
Av.	8.56	8.33	8.44	8.99	6.074	6.449	6.11	6.34	6.614	

Note: *Values that do not have the same superscript letters differ significantly at the 5% level

We can conclude from the results of the two growing seasons that reducing the required irrigation by 30% resulted in a non-significant yield reduction of 2% (101 kg/ha). saved irrigation water, and improved water productivity. The water saved was144 mm (21.5%) and the WP improved by 0.427kg/m^3 (31%) as compared to the farmers' irrigation practices.

The irrigation water saved in the 2005-2006 season by growing wheat on hills in raised beds varied from 140 mm (25%) to 167 mm (33%), as compared to the farmers' irrigation practices. For the 2006-2007 season the comparable amount of water saved ranged from 87 mm (20%) to 85 mm (27%). Also, the modified raised bed intervention (broadcasting) used between 182 mm (27%) and 75 mm (17%) less water, than that applied by the farmers' irrigation practices. For all the farms, the irrigation water saved amounted to 145 mm (26.3%) for raised bed hills and 132 mm (22.7%) for raised bed broadcasting (see Table 1.11).

Planting wheat on raised bed hills (RBh) increased grain yield by 13% over the yield resulting from the farmers' practices during the 2005-2006 season. For the 2006-2007 season the increase was about 7% over that obtained following the farmers' irrigation practices. For the raised bed broadcasting (RBb) method, the significant increase in wheat grain yield ranged from 177 kg/ha (3%) for Farm 3 to 1310 kg/ha (20%) for Farm 5. The increase attributed to the raised bed broadcasting intervention was from 177 kg/ha (3%) to 1310 kg /ha (20%). For all farms, implementing RBh and RBb resulted in higher wheat grain yields over the farmers' irrigation practices. The RBh approach resulted in a 366 kg/ha (6%) increase and the RBb one produced a 731 kg/ha (11.7%) improvement (see Table 1.12).

Tables 1.13 and 1.14 and Figure 1.7 show the effect of using both raised beds (in hills or broadcasting) on wheat irrigation water productivity at old land sites compared to the deficit and the farmers' irrigation practices during the 2005-2006 and 2006-2007 seasons.

Generally, besides saving water and increasing yields, deficit irrigation in old land recorded higher water productivity. The average water productivity of the farmers' traditional practices was 1.60 kg/m^3 in 2005-2006 and 1.132 kg/m^3 in 2006-2007. The water productivities following the deficit irrigation in these seasons were, respectively, 1.588 kg/m^3 (a 25% increase) and 2.0 kg/m^3 (a 40% increase).

In the 2005-2006 season, the water productivity achieved with the farmers' practices ranged from 1.37 kg/m^3 to 1.75 kg/m^3; compared to the 2.07 kg/m^3 to 2.66

Table 1.13. Effect of interventions on WP for wheat in old land sites.

Farm	WP 2005-2006 (kg/m^3)				WP 2006-2007 (kg/m^3)					
	Farmer	Req	0.7 req	RB_h	Farmer	Req	0.7 req	RB_h	RB_b	Basin
1	1.75	1.68	2.17	2.24	0.898	1.075	1.339	1.321	1.353	0.856
2	1.37	1.51*	1.72	2.07	0.96	1.148	1.379	1.326	1.381	
3	1.52	1.53	1.63	2.44	1.048	1.125	1.318	1.323	1.337	
4	1.75	1.52	2.49	2.66	1.098	1.452	1.813	1.652	1.670	
5					1.478	1.659	2.086	1.890	2.154	0.876
Av.	1.60^{c}	1.56^{c}	2.00^{b}	2.35^{a}	1.096	1.292	1.587	1.502	1.579	0.866

Note: RBh – raised bed hills; RBb – raised bed broadcasting.
*Values that do not have the same superscript letters differ significantly at the 5% level.

Table 1.14. Average amount of water applied, yield, and WP for wheat in old lands.

	Year	Farmer	Req	0.7 req	RB_h	RB_b	Basin
Average amount of water applied (mm)	2005-2006	537	534	420.	384		
	2006-2007	582	521	410	445	450	614
	Average	559	528	415	415	450	614
Relative amount of water applied	2005-2006	1	99.45	77.03	71.5		
	2006-2007	1	89.5	78.7	76.5	77.3	106
	Average	1	94.49	77.86	74.0	77.30	105.5
Average yield (t/ha)	2005-2006	8.56	8.33	8.44	8.9		
	2006-2007	6.421	6.58	6.33	6.6	6.942	5.46
	Average	7.491	7.456	7.39	7.8	6.94	5.46
Relative yield	2005-2006	1	98.45	97.9	106.4		
	2006-2007	1	102	99	102.0	108	85
	Average	1	100.23	98.45	104.2	108.0	85.00
Average water productivity (kg/m^3)	2005-2006	1.6	1.56	2	2.4		
	2006-2007	1.095	1.294	1.588	1.5	1.579	0.889
	Average	1.348	1.427	1.794	1.925	1.579	0.889
Relative water productivity	2005-2006	1	0.98	1.25	1.47		
	2006-2007	1	1.18	1.45	1.37	1.44	0.81
	Average	1	1.06	1.33	1.43	1.17	0.66

Note: RBh – raised bed hills; RBb – raised bed broadcasting.

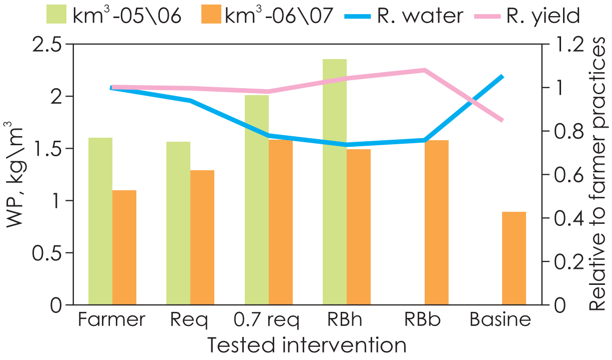

Figure 1.7. Average and relative amounts of water applied, wheat yield, and WP in the old lands during the 2005-2006 and 2006-2007 seasons.

kg/m³ yield range for RBh. In the 2006-2007 season the figures were 0.898 kg/m³ to 1.478 kg/m³ for the farmers' practices against 1.321 kg/m³ to 1.89 kg/m³. Comparable values for RBb were 1.337 kg/m³ to 2.154 kg/m³. For all farms, the water productivities were 1.5 kg/m³ for RBh, 1.57 kg/m³ for RBb, and 1.133 kg/m³ for the farmers' irrigation practices. Generally, raised beds that saved considerable amounts of irrigation water. produced higher wheat grain yields, and increased WP compared to the farmers' traditional practices.

It is worth mentioning that the traditional farmers' irrigation practices, i.e., basin irrigation, used more irrigation water than raised bed irrigation and, significantly, gave lower wheat grain yields. The reduction in yield was 1730 kg/ha for Farm 1 and 114 kg/ha for Farm 5. So, for the two farms, water productivity was reduced by 0.043 kg/m³ (5%) and 0.6 kg/m³ (41%) by following the traditional practice of planting on hills with furrows between them.

The results from the two seasons lead to the conclusion that planting wheat on raised beds in hill or broadcasting saved not less than 109 mm (23%) of water, increased yields by 279 kg/ha (6%), and increased WP by 0.558 kg/m³ (41%) over the farmers' traditional irrigation practices.

1.3.2 Berseem

The effects of different water treatments on the yield of one cut are given in Table 1.15 for the 2005-2006 season. The date of this cut was March 4, 2006 for Farm 2 and May 4, 2006 for Farm 5. It is clear that the two farmers applied excessive amounts of irrigation water – for Farm 2, 93.3 mm against a required amount of 82.1 mm and for Farm 5, 59.5 mm against a required amount of 49.5 mm. If the required amount of water had been applied it would have saved Farm 2 12% of the irrigation water and Farm 5, 16.8%. Also it would have increased the fresh weight from 20% to 30 % and the dry weight from 16% to 31% as compared with the farmers' practices. The amounts of water applied under deficit irrigation (70% of the full irrigation treatment) were 57.6 mm and 40.7 mm. The amounts of water saved were 38.16% (Farm 2) and 31.6% (Farm 5). However, the fresh yield increase ranged from 7.2% to 22% and the increase in dry weight was from 1.4% to 19.6 %.

The effect of irrigation treatments on the water productivity of fresh and dry yields of berseem are given in Table 1.16. The data show that, on average, the productivity (fresh weight) in kg/m³ of water applied was 50.4 for the farmers' practices, 74.6 for full irrigation, and 88.8 for 70% of full irrigation. Hence, besides saving water by irrigating berseem with 70% of the full irrigation amount, this treatment produced a higher yield from each cubic meter of water applied compared to the other treatments.

1.3.3 Maize

From Tables 1.17 and 1.18, the average amounts of water saved for 2006 and 2007 for all farms, were 161 mm (26%) and 160 mm (20%). The non significant corn yield reductions amounted to 1200 kg/ha (12%) and 445 kg/ha (4%) under the 70% of full irrigation regime. The 75% of full irrigation regime saved between 111 mm and 207 mm (19% to 32%) of water in 2006 and

Table 1.15. Effect of irrigation treatments on relative amount of water applied, yield, and relative yield for one cut of berseem at the old lands, 2005-2006.

Treatments			Farmer	Full irrigation	0.7 req
Farm 2	Amount of water applied (mm)		93.3	82.1	57.6
Farm5			59.5	49.5	40.7
Farm 2	Relative amount of water applied		100	88.00	61.74
Farm5			100	83.19	68.40
Farm 2	Yield (t/ha)	Fresh	41.293	49.632	44.268
		Dry	5.307	6.164	5.379
Farm5		Fresh	33.558	43.839	40.936
		Dry	3.760	4.927	4.498
Farm 2	Relative yield	Fresh	100	120.19	107.216
		Dry	100	116.15	101.36
Farm5		Fresh	100	130.64	121.99
		Dry	100	131.04	119.63

Table 1.16. Effects of tested interventions on the WP of one cut of berseem in the in 2005-2006 season.

Farmer's name	Dryness	Farmer practice (kg/m^3)	Full requirement (kg/m^3)	0.7 full requirement (kg/m^3)
Dadr	Fresh (F)	44.3	60.5	76.9
	Dry (D)	5.7	7.5	9.3
Dosoky	Fresh (F)	56.4	88.6	100.6
	Dry (D)	6.3	10.0	11.1
Average	Fresh (F)	50.4	74.6	88.8
	Dry (D)	6.0	8.5	10.2

from 151 mm to 174 mm (19% to 21%) of water in 2007. The corresponding average reductions in yield for Farms 4 and 5 were 12% and 3.4%.

It can be seen that the 70% of full irrigation regime improved water use efficiency. In 2006 it increased water productivity by not less than 0.119 kg/m^3 (8%) and not more than 0.507 (35%) kg/m^3 compared to the farmer's traditional practices. For 2007, deficit irrigation increased water productivity by not less than 0.229 kg/m^3 (14%) and not more than 0.485 kg/m^3 (33%).

Compared to the full irrigation requirement treatment, the excess water applied by the farmers was 86 mm (10%) in the 2005-2006 season and 47 mm (7 %) in the 2006-2007 season. Also the irrigation

Table 1.17. Effects of different water regimes on yield and WP of maize at Monofia (old lands) in the 2006 season.

	Farmer practice	Req	0.70 req	$W.F_h$	Aver	Farmer practice	Req	0.7 req	$W.F_h$	Aver
	Yield (t/ha)					**Relative yield**				
Farm 1 Khatab	10.1^{a}	10^{a}	9.64^{ab}	10.5^{a}	10.1^{a}	1	0.99	0.95	1.040	0.99
Farm 2 Badr	9.41^{ab}	8.23^{cd}	7.75^{cd}	7.23^{d}	8.2^{b}	1	0.87	0.82	0.768	0.82
Farm 3 Sobhy	9.64^{ab}	8.06^{cd}	7.69^{cd}	9.44^{ab}	8.7^{b}	1	0.84	0.80	0.979	0.87
Farm 4 Kamal	9.28^{bc}	9.08^{bc}	8.55^{bc}	9.15^{bc}	9.0^{b}	1	0.98	0.92	0.986	0.96
Average	9.61^{a}	8.84^{a}	8.41^{a}	9.08^{a}	9.0	1	0.92	0.88	0.945	0.91
	Amount of water applied (mm)					**Relative amount of water applied**				
Farm 1 Khatab	574	564	463	451	513	1	0.98	0.81	0.786	0.86
Farm 2 Badr	656	600	499	483	560	1	0.91	0.76	0.736	0.80
Farm 3 Sobhy	655	563	483	498	550	1	0.86	0.74	0.760	0.79
Farm 4 Kamal	648	550	441	464	526	1	0.85	0.68	0.716	0.75
Average	633	569	472	474	537	1	0.90	0.74	0.749	0.80
	Water use efficiency (kg/m^3)					**Relative water use efficiency**				
Farm 1 Khatab	1.760	1.773	2.082	2.328	2.0	1	1.01	1.18	1.323	1.17
Farm 2 Badr	1.434	1.372	1.553	1.497	1.5	1	0.96	1.08	1.044	1.03
Farm 3 Sobhy	1.472	1.432	1.592	1.896	1.6	1	0.97	1.08	1.288	1.11
Farm 4 Kamal	1.432	1.651	1.939	1.972	1.7	1	1.15	1.35	1.377	1.29
Average	1.524	1.557	1.792	1.923	1.7	1	1.02	1.18	1.262	1.15

Note: + (a,b,cd) : Numbers followed by the same letter are not statistically different at a < 5%.

Table 1.18. Effect of different water regimes on yield and WP of maize at Monofia (old land) in the 2007 season.

	Farmer practice	Req	0.7 req	$W.F_h$	WF_b	Farmer practice	Req	0.7 req	$W.F_h$	WF_b
	Yield (t/ha)					**Relative yield**				
1	8.86	8.68	8.48	8.86		1	0.98	0.96	1	
2	11.5	12.235	12.294	12.824		1	1.06	1.07	1.12	
3	15.86	16.4	14.35	16.46		1	1.03	0.9	1.04	
4	12.29	14.76	12.01	14.24		1	1.2	0.98	1.16	
5	12.63	13.43	11.58	12.87	12.47	1	1.06	0.92	1.02	0.99
Aver	12.228	13.101	11.743	13.051	12.47	1	1.066	0.966	1.068	0.99
	Amount of water applied (mm)					**Relative amount of water applied**				
1	825	761	651	676		1	0.92	0.79	0.82	
2	776	740	625	619		1	0.95	0.81	0.8	
3	758	708	600	592		1	0.93	0.79	0.78	
4	820	783	666	685		1	0.95	0.81	0.84	
5	796	752	635	631	688	1	0.94	0.8	0.79	0.86
Aver	795	748.8	635.4	640.6	688	1	0.938	0.8	0.806	0.86
	Water use efficiency (kg/m^3)					**Relative water use efficiency**				
1	1.074	1.141	1.303	1.311		1	1.06	1.21	1.22	
2	1.482	1.653	1.967	2.072		1	1.12	1.33	1.4	
3	2.092	2.316	2.392	2.78		1	1.11	1.14	1.33	
4	1.499	1.885	1.803	2.079		1	1.26	1.2	1.39	
5	1.587	1.786	1.824	2.04	1.813	1	1.13	1.15	1.29	1.14
Aver	1.547	1.756	1.858	2.056	1.813	1	1.136	1.206	1.326	1.14

water requirement treatment resulted in a WP between 2% and 13% higher than that associated with the farmers' irrigation practices.

From Tables 1.19 and 1.20 the average yield of the three interventions for the four farmers showed no significant difference in corn yield from that achieved following the farmers' usual irrigation practices. The amount of water, saved over that used in the traditional practice was between 123 mm and 184 mm (between 21% and 28%). In 2006, except for Farm 2, the yield of corn from raised-seed beds (between 7.23 t/ha and 10.5 t/ha) was not significantly different from that of the farmers' usual practices (between 9.28 t/ha and 10.1 t/ha). In 2007, the wide furrow method, which saved between 149 mm and 165 mm (between 18% and 21%) of water, significantly increased the yield over that obtained following the farmers' normal practices by between 240 kg/ha and 1950 kg/ha. In other words, from the results of the two seasons, the wide furrow method saved an appreciable amount of irrigation

Table 1.19. Effect of different water application regimes on the yield and WP of maize at Monofia (old lands) in the 2006 season.

	Farmer practice	Req	0.70 req	$W.F_h$	Aver	Farmer practice	Req	0.7 req	$W.F_h$	Aver
	Yield (t/ha)					Relative yield				
1	10.1^{a}	$10^{(a)}$	9.64^{ab}	10.5^{a}	10.1^{a}	1	0.99	0.95	1.040	0.99
2	9.41^{ab}	8.23^{cd}	7.75^{cd}	7.23^{d}	8.2^{b}	1	0.87	0.82	0.768	0.82
3	9.64^{ab}	8.06^{cd}	7.69^{cd}	9.44^{ab}	8.7^{b}	1	0.84	0.80	0.979	0.87
4	9.28^{bc}	9.08^{bc}	8.55^{bc}	9.15^{bc}	9.0^{b}	1	0.98	0.92	0.986	0.96
Aver	9.61^{a}	8.84^{a}	8.41^{a}	9.08^{a}	9.0	1	0.92	0.88	0.945	0.91
	Amount of water applied (mm)					Relative amount of water applied				
1	574	564	463	451	513	1	0.98	0.81	0.786	0.86
2	656	600	499	483	560	1	0.91	0.76	0.736	0.80
3	655	563	483	498	550	1	0.86	0.74	0.760	0.79
4	648	550	441	464	526	1	0.85	0.68	0.716	0.75
Aver	633	569	472	474	537	1	0.90	0.74	0.749	0.80
	Water use efficiency (kg/m³)					Relative water use efficiency				
1	1.760	1.773	2.082	2.328	2.0	1	1.01	1.18	1.323	1.17
2	1.434	1.372	1.553	1.497	1.5	1	0.96	1.08	1.044	1.03
3	1.472	1.432	1.592	1.896	1.6	1	0.97	1.08	1.288	1.11
4	1.432	1.651	1.939	1.972	1.7	1	1.15	1.35	1.377	1.29
Aver	1.524	1.557	1.792	1.923	1.7	1	1.02	1.18	1.262	1.15

Note: + $^{(a,b,cd)}$: Numbers followed by the same letter are not statistically different at $\alpha < 5\%$.

water compared by that used by the farmers following their usual practices, while producing nearly the same yield.

It is evident that the raised-seed bed with wide furrow gave higher water productivity, amounting to 0.399 kg/m³ (26%) and 0.509 kg/m³ (33%) over farm irrigation practices for the first and second seasons, respectively.

It can be seen that using wide furrows increased water productivity over the farmers' irrigation practices between 0.063 kg/m³ (4.4%) and 0.568 kg/m³ (37.7%) during the 2006 season and from 0.237 kg/m³ (22%) and 0.688 kg/m³ (40%) in the 2007 season.

1.3.4 Cotton

Table 1.21 presents the effects of various interventions on cotton yield, amount of irrigation water applied, and water productivity at the old lands for the 2006 and 2007 seasons. The data indicate that planting cotton on wide furrows resulted in a not significant reduction of 370 kg/ha (8%) in seed yield in the 2006 season and a not significant increase of 225 kg/ha (7%) in the 2007 season. The amounts of water saved as compared with the farmers' usual practices amounted to 112 mm (25%) in 2006 and 347

Table 1.20. Effect of different water application regimes on yield and WP of maize at Monofia (old lands) in the 2007 season.

	Farmer practice	Req	0.7 req	$W.F_h$	WF_b	Farmer practice	Req	0.7 req	$W.F_h$	WF_b
	Yield (t/ha)					**Relative yield**				
1	8.86	8.68	8.48	8.86		1	0.98	0.96	1	
2	11.5	12.235	12.294	12.824		1	1.06	1.07	1.12	
3	15.86	16.4	14.35	16.46		1	1.03	0.9	1.04	
4	12.29	14.76	12.01	14.24		1	1.2	0.98	1.16	
5	12.63	13.43	11.58	12.87	12.47	1	1.06	0.92	1.02	0.99
Aver	12.228	13.101	11.743	13.051	12.47	1	1.066	0.966	1.068	0.99
	Amount of water applied (mm)					**Relative amount of water applied**				
1	825	761	651	676		1	0.92	0.79	0.82	
2	776	740	625	619		1	0.95	0.81	0.8	
3	758	708	600	592		1	0.93	0.79	0.78	
4	820	783	666	685		1	0.95	0.81	0.84	
5	796	752	635	631	688	1	0.94	0.8	0.79	0.86
Aver	795	748.8	635.4	640.6	688	1	0.938	0.8	0.806	0.86
	Water use efficiency (kg/m^3)					**Relative water use efficiency**				
1	1.074	1.141	1.303	1.311		1	1.06	1.21	1.22	
2	1.482	1.653	1.967	2.072		1	1.12	1.33	1.4	
3	2.092	2.316	2.392	2.78		1	1.11	1.14	1.33	
4	1.499	1.885	1.803	2.079		1	1.26	1.2	1.39	
5	1.587	1.786	1.824	2.04	1.813	1	1.13	1.15	1.29	1.14
Aver	1.547	1.756	1.858	2.056	1.813	1	1.136	1.206	1.326	1.14

mm (22%) in 2007. This treatment improved water productivity by 0.237 kg/m^3 (23%) in 2006 and 0.110 kg/m^3 (37%) in 2007.

1.4 Conclusions

- The results of the on-farm trials showed that recommended irrigation techniques are simple techniques that can be easily implemented by the farmers. They can lead to a significant increase in the yield, crop water productivity, and in the amounts of water saved as compared with those obtained following the farmers' traditional practices.
- Deficit irrigation is a technique that has shown a beneficial effect in maximizing crop water productivity. The results of the trials carried showed that the implementation of such a technique, where a relatively high proportion of the irrigation water is saved, did not result in any significant losses in yield for the major crops.
- The raised bed technique showed very satisfactory results on the different sites

Table 1.21. Effects of different water application regimes on the yield and WP of cotton at Monofia (old lands) in the 2006 and 2007 seasons.

	2006					2007			
	Farmer practice	Req	0.7req	$W.F_h$	LSD	Farmer practice	Full	0.7 full	$W.F_h$
Yield (t/ha)	4.51	4.81	4	4.14	NS	3.261	3.636	3.299	3.486
Amount of water applied (mm)	440	461	347	328		1110	1059	870	863
Water productivity (kg/m³)	1.025	1.043	1.153	1.262		0.294	0.343	0.379	0.404
Relative yield	1	1.07	0.89	0.92		1	1.11	1.01	1.07
Relative amount of water applied	1	1.05	0.79	0.75		1	0.95	0.78	0.78
Relative water productivity	1	1.02	1.12	1.23		1	1.17	1.29	1.37

investigated (old lands and marginal lands) with the main winter (wheat and berseem) and summer (corn and cotton) crops. This technique, besides saving around 30% of the amount of water applied, increased crop production by nearly 10% over the farmers' traditional irrigation practices. Furthermore, the implementation of such a simple technique resulted in average water saving amounting to between 20% and 25% of that corresponding to the basin irrigation practice of the farmers.

- The trials conducted on wheat during the growing season 2006-2007 in the old lands sites allowed verification of the validity of the hypothesis that we can produce the same yield (or even more) by using less water. Irrigating wheat with a volume of water corresponding to 70% of that usually applied by the farmers showed that the yield was not significantly affected – a notable improvement in the crop water productivity. The results showed that the average WP was 40% greater than that recorded under the traditional irrigation practices.
- Berseem is the second major winter crop. The research findings in the trials conducted in the old lands indicated that such a crop could be successfully grown under deficit irrigation techniques, because it responded like the wheat crop. For berseem, deficit irrigation reduced the amount of seasonally applied water by nearly 44% of that applied by the farmers, with a reduction in yield not exceeding 12% and an increase in water productivity of 33%.
- When corn was irrigated with 70% of the required amount of water, the average loss in yield was about 8% as compared to that obtained following the farmers' usual irrigation practices. This significant water saving, while maintaining yield values very near to those obtained under traditional practices, resulted in an increase in crop water productivity of nearly 20%.
- Cotton could be produced successfully by reducing the volume of irrigation water applied. Irrigation of cotton with volumes of water corresponding to 70% of the required amount resulted in a yield reduction corresponding to 10% of the yield obtained under the farmer's irrigation practices.

Chapter 2: improved water and land productivities in the saline areas of the Nile Delta

Chapter 2: improved water and land productivities in the saline areas of the Nile Delta

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2.1 Characteristics of the saline areas

The study was conducted in El-Serw (New Alexandria) located about 32 km south of Damietta, Damietta Governorate as shown in Figure 2.1. El-Manzala Lake is to the east, Dakahlia Governorate lies to the south, and to the west are El-Sharqawia canal and the Nile River.

The selected site has the general characteristics of marginal lands:

- Drainage system problems
- High water table
- Increased soil salinity
- Seawater intrusion
- Pollution due to extensive use of chemicals; low water quality
- Available water increases relatively in winter
- Tail-end canal problems become less acute, especially in summer
- All farmers use surface irrigation systems.

The area under study is about 8000 ha, which represents about 15% of the total cultivated area. According to the Agricultural Census of 2000, the area of El-Talamza is about 342 feddan, El-Sibakhat is about 871 feddan and the ‘Out of area served’ region is about 498 feddan

2.1.1 Soil characteristics

Marginal lands (salt affected soils) are irrigated with fresh water, drainage water, and a mix of the two. Such soils are generally of high salinity and/or have a high exchangeable sodium percentage (ESP) in the case of alkalinity problems. Soils exhibiting both problems are termed as saline alkali soil (Table 2.1).

Figure 2.1. The marginal lands site location at El-Serw.

Table 2.1. Fertility and the physical and chemical analyses of the soils of the marginal lands, El-Serw.

Farm	N (ppm)	P (ppm)	K (ppm)	Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)	pH (1:2.5)	EC (dS/m)	ESP
1	36	11.2	570	5.48	18.51	26.43	49.58	8.1	1.9	3.5
2	35	10.1	600	5.75	13.15	32.28	48.22	8.3	2.2	3.4
3	40	12.0	620	4.27	13.49	37.95	44.29	8.2	1.8	1.8
4	33	9.8	680	5.29	16.86	32.41	45.44	8.4	2.8	18.6
5	34	10.6	510	4.28	12.6	28.02	55.46	8.0	9.5	16.2
6	50	11.8	520	6.48	25.16	25.58	42.42	8.0	6.8	16.8

Note: EC – electrical conductivity

Considering the marginal soil analysis (Table 2.1), it is quite clear that El-Serw site is, in general, characterized by a high clay content (between 48% and 55%) and high pH values – ranging between 8.0 and 8.4 with an average value of 8.16. The soils from the six farms in the investigation were tested and found to vary from one farm to the other. The soils of Farms 1, 2, 3, and 4 were slightly affected by salinity, with an EC value ranging between 1.8 and 2.8 dS/m (average 2.17 dS/m) while those of Farms 5 and 6 had high EC readings (6.8 – 9.5 dS/m) as well as high ESP values (16.2 to 18.6) indicating that both farms are located on saline-alkaline soils.

2.1.2 Soil and soil fertility improvement practices

The three groups of farmers called: El-Talamza, El-Sebakhat and Out of area served. use manure and chemical fertilizers to improve the soil and soil fertility as illustrated in Table 2.2. Applications of manure and fertilizer are the most common methods, while gypsum ranks second, and drainage and sub-soiling rank third among the fertility management practices in the three groups.

All farmers in the three groups have salinity problems on their lands. However, there are many treatments to maintain the soil in a good quality. In general, most farmers apply the Mole method for drainage in addition to main and branches drains. In the case of soil fertility, most farmers, except the 'Out of area served' group, add manure and chemical fertilizers.

2.1.3 Farmers selection procedures

A sample of 30 farmers was interviewed. The farmers were selected from 3 different groups located across El-Shoka canal, Khodry canal, Anber drain and El-Serw main drain, and they are spatially distributed as follows:

- The first group, referred to as El-Talamza group, consists of farms where fresh water is the main source for irrigation;
- The second group, referred to as El-Sebakhat group, consists of farms where fresh water and drainage water from the

Table 2.2. Quantity applied of fertilizer per feddan in the three groups.

Item	El-Talamza	El-Sebakhat	Out of area served
Manure:			
Availability	No	Yes	Yes
Application	Yes	Yes	Yes
Quantity (m^3)	8	8	12
Cost (EGP/m^3)	10	10	10
Leaf fertilizer:			
Application	No	Yes	No
Chemical fertilizer (50 kg bag):			
Urea 46.5%	3	3	3
Ammonium nitrate 33.5%			
Ammonium sulfate 20%			
Mono Superphosphate 15.5%	3	4	3
Potassium 48%			

Source: Checklist of the Participatory Rural Appraisal report.

Anber drain and El-Serw main drain are the main sources for irrigation;

- The third group, referred to as 'Out of area served' (Kharerg El-Zemam) group, consists of farms where the drainage water of the El-Serw main drain is the main source for irrigation.

Farmers were selected from three different groups located across the El-Shoka canal and El-Serw main drain. Three basins were selected, referred to as groups El-Talamza, El-Sebakhat and 'Out of area served.

A sample of 16 farmers was selected to monitor the biophysical and socioeconomic parameters – 6 farmers in El-Talamza group, and 5 farmers each for El-Sebakhat group and the 'Out of area served' group. The selected farmers were interviewed twice a year to collect socioeconomic information.

2.2 Characteristics of the community

2.2.1 Farm size

There are not too many variations in farm size among the farmers in the 3 groups. For example, in El-Talamza group, the average farm size is estimated at 3.5 feddan. The average farm size in El-Sebakhat group is estimated at 4.2 feddan, while that for the 'Out of area served' group is estimated at 2.6 feddan.

2.2.2 Family size and workforce

In El-Talamza group, the family size ranges between 0.8-6.2 HCU, with an average of 3.8. However, the family size in El-Sebakhat group ranges between 1.8 and 8.6 HCU, with an average of 4.6. For the 'Out of area served' group, family size ranges between 2.6 and 14.8 HCU, with an average of 7.0. The 'Out of area served' group has the largest labor families in terms of Human Labor Units.

2.2.3 Structural ratios

The average land size available per family member (the feddan of cultivated area per human consumption unit, or CA/HCU) in El-Talamza group is 0.9 feddan. For El-Sebakhat group this ratio is estimated at 0.9 feddan and for the 'Out of area served' group it is estimated at 0.4 feddan. In contrast, the average family labor unit available per feddan of cultivated area (HLU/CA) is 0.26 for El-Talamza group and 0.29 for El-Sebakhat group. The HLU/CA values for the groups is less than that for the 'Out of area served' group, consequently they have higher needs for hired labor. The structural ratios are summarized in Table 2.3

2.2.4 Livestock holding

Most farmers (82%) have animals. The herd size is illustrated in Table 2.3.

2.2.5 Farmer's income

Tables 2.4 and 2.5 show that farmers in El Serw area consider field crops and livestock as the main sources of agricultural income for both winter and summer.

2.2.6 Cropping patterns

Table 2.6 shows that rice and cotton are the main summer crops while wheat and berseem are the main winter crops for the three groups.

Most farmers practice two-year crop rotations. There are four main crop rotations for the three groups:

- Berseem/rice
- Berseem/cotton
- Wheat/cotton
- Wheat/rice
- Area under production

Table 2.7 shows some economic indicators of the winter crops for the three groups, while Table 2.8 illustrates those of the summer crops for the three groups.

2.2.7 Crop varieties

In addition to cotton, the wheat varieties planted by the three groups were Sakha 103, Sakha 104 and Sakha 93 and the rice varieties were Hybrid 1 and Hybrid 31.

2.2.8 Water management and supply

There are variations in El-Serw water supply and quality among farmers, depending on the distances of their fields from the source. Water problems differ according to whether the farm is located on the canal or the mesqa.

Table 2.3. Structural ratios of the three groups.

Group	Average farm size (feddan)	HCU	CA/HCU	LU	HLU	HLU/CA
El-Talamza	3.5	3.8	0.9	2.9	0.9	0.26
El-Sebakhat	4.2	4.6	0.9	4.9	1.2	0.29
Out of area served	2.6	7	0.4	4.6	2.7	1.04

Note: HCU – Human Consumption Unit; HLU – Human Labor Unit; LU – Livestock Unit.
Source: Collected and calculated from the multidisciplinary survey.

Table 2.4. Income earned (EGP) from different activities for the three groups in the winter seasons 2005 and 2006.

Group	Farmer code no.	Season 2005				Season 2006			
		Field crops	Livestock	Off-farm income	Total income	Field crops	Livestock	Off-farm income	Total income
El-Talamza	1	12,000	4,800	7,000	23,800	31,865	21,243		53,108
	2	2,500	4,500		7,000	7,570	7,570	6,000	13,570
	3	1,800	3,600		5,400	2,300	300		2,600
	4	22,000			22,000	23,800	2,644		13,076
	5	4,000	4,000		8,000	6,538	6,538		13,076
	6	4,500		5,000	9,500	3,645			3,645
	Av.	7,800	2,817	2,000	12,617	12,620	6,383	1,000	16,513
El-Sebakhat	1	22,000	5,000		27,000	22,176	2,772		24,948
	2	6,000	1,500		7,500	12,110	3,027	7,000	22,137
	3	5,000	1,000	4,000	10,000	6,74	1,593	7,000	14,967
	4	15,000	5,000	6,000	26,000	16,415	4,103	6,000	26,518
	5	24,000	6,000		30,000	30,290	12,981		43,271
	Av.	14,400	3,700	2,000	20,100	17,473	4,895	4,000	26,368
Out of area served	1	6,000	2,400	5,000	13,400	7,175	1,793	4,000	12,968
	2	3,500		1,000	4,500	8,720			8,720
	3	6,000			6,000	6,000			6,000
	4	5,000			5,000	5,100		7,000	12,100
	5	1,700	600	2,000	4,300	1,830	457	2,000	4,287
	Av.	4,440	600	1,600	6,640	5,765	1,125	2,600	8,815

Source: Data survey.

Table 2.5. Income earned (EGP) from different activities for the three groups in the summer seasons 2005 and 2006.

Group	Season 2005				Season 2006			
	Field crops	Livestock	Off-farm income	Total income	Field crops	Livestock	Off-farm income	Total income
El-Talamza	7,800	2,817	2,000	12,617	12,620	6,383	1,000	16,513
El-Sebakhat	14,400	3,700	2,000	20,100	17,473	4,895	4,000	26,368
Out of area served	4,440	600	1,600	6,640	5,765	1,125	2,600	8,815

Source: Data survey.

Table 2.6. Cropping patterns for the three groups.

Group	Summer 2004-2005	Winter 2004-2005	Summer 2006	Winter 2006-2007
El-Talamza	Rice, cotton	Wheat, berseem	Rice, cotton	Wheat, berseem, faba bean
El-Sebakhat	Rice, cotton	Wheat, berseem	Rice, cotton	Wheat, berseem
Out of area served	Rice, cotton	Wheat, berseem, Sugar beet	Rice	Wheat, berseem

Source: Collected and calculated from the multidisciplinary survey.

El-Talamza group and El-Sebakhat group receive fresh, good quality irrigation water in the winter season, but there is a shortage of water in summer, especially in May, June, and July. At this time the farmers use drainage water from El-Serw and Anber drains. Even though the water quality of the latter is very bad they do not have any other source. Farmers in the 'Out of area served' group depend on El-Serw drain for irrigation.

Farmers in the three groups do not have any water table problems except in May, June, and July. They solve any water problems by allocating irrigation time among themselves.

2.2.9 Pests and weeds control

Weeds are found in the fields of the three groups. The manure and the water used on the fields are the main reasons for this infestation. Farmers of El-Talamza group apply herbicides to control weeds. El-Sebakhat group farmers weed by hand while the 'Out of area served' group farmers use both herbicides and hand weeding. Cotton leaf worm and red worm are the main plant pests for the three groups and they apply chemicals to control these pests.

Farmers in the three groups have difficulties in getting technical information. El-Talamza group and El-Sebakhat group rely on their own experiences. The 'Out of area served' group gets information from the agricultural station.

2.2.10 Land productivity

Total production was recorded to evaluate the impacts of the project. Tables 2.9 and 2.10 show the total winter and summer production for the three groups.

Table 2.11 shows that the productivity of the second and third groups is higher than that of the first group for all crops, except for berseem.

2.3 Objectives and methodologies

2.3.1 Winter crops

Wheat

- Farmers' irrigation practices
- Full irrigation (ET+0.2ET for leaching or more according to salinity), basin irrigation
- 70% of full irrigation, basin irrigation
- Wide furrow after broadcasting.

Berseem (dry and wet planting)

The traditional method for planting berseem is to broadcast wet seed on flooded land. This method increases

Table 2.7. Area under production for the three groups in winter.

Group	Farmer code No.	Crops	Area in 2005 (feddan)	Area in 2006 (feddan)
El-Talamza	1	Wheat	2.52	2.1
		Berseem	2.39	2.38
		Faba bean		0.42
	2	Wheat	0.35	0.42
		Berseem	0.35	0.4
		Faba bean	0.12	
	3	Wheat		0.13
		Berseem	3.7	
	4	Berseem	2.1	0.24
		Wheat	2.35	2.1
	5	Sugar beet		2.35
		Wheat	0.42	
	6	Wheat	0.42	0.84
		Berseem	0.42	0.42
El-Sebakhat	1	Wheat		0.42
		Berseem	0.42	1.79
	2	Wheat	0.84	1.68
		Berseem	0.42	0.84
	3	Wheat	0.95	0.84
		Berseem		0.42
	4	Wheat	1.26	0.56
		Berseem	1.63	1.68
	5	Wheat	1.26	1.68
		Berseem	2.1	1.68
		Sugar bee	0.42	
Out of area served	1	Berseem	1.05	1.68
		Wheat	0.42	
	2	Berseem	0.84	1.47
	3	Wheat		1.68
		Berseem	0.84	
	4	Wheat	0.84	0.84
	5	Wheat	0.21	0.84
		Berseem	1.05	

Source*:* Monitoring and Evaluation (M&E) Survey Report.

Table 2.8. Area under production for the three groups in summer.

Group	Farmer code no.	Area for rice (feddan)			Area for cotton (feddan)		
		2004	2005	2006	2004	2005	2006
El-Talamza	1	6	10	11	6	2	1
	2	1.96	1.3	0.96	0	0.63	1
	3	0.88	0.88	0.88	0	0	0
	4	11	11	11	0	0	0
	5	2	2	1	0	0	1
	6	2	2	1.5	0	0	0
El-Sebakhat	1	5	5.2	6.25	3.4	4	2
	2	2	2	2	2	2	2
	3	0	1.2	1.2	2.3	1.2	1.2
	4	3	5	5.5	3.88	2	1.5
	5	6.5	6	5	3	3.5	4.5
Out of area served	1	3.5	3.5	3.5	0	0	0
	2	2	2	4	0	0	0
	3	2	2	2.5	0	0	0
	4	2	2	2	0	0	0
	5	1	1	1	0	0	0

Source: Monitoring and Evaluation (M&E) Survey Report.

water losses through evaporation and percolation. A new planting approach was applied – dry seeds were planted on dry soil with the same plant density as in the traditional method. This method insured uniformity of water distribution in the field and led to increased productivity. In addition, it saved an application of water and decreased the irrigation costs.

- Farmers' irrigation practices
- Full irrigation (ET+0.2ET for leaching requirements)
- 70% of full irrigation.

2.3.2 Summer crops

Rice

- Farmers' practices
- Irrigation every four days with 7 cm depth
- Irrigation every eight days with 7 cm depth

Cotton

- Farmers' practices
- Full irrigation
- 70% of full irrigation

Table 2.9. Total winter production for the three groups.

Group	Farm code	Crops	Production 2004-2005 (t/ha)	Production 2005-2006 (t/ha)
EL-Talmza	1	Wheat	37.5	30
		Berseem	213.75	250
		Faba bean		3.5
	2	Wheat	4.675	7
		Berseem	62.25	62.5
		Faba bean	0.35	
	3	Wheat		3
		Berseem	34.8	
	4	Berseem	30.8	50
		Wheat	312.5	30
	5	Sugar beet		450
		Wheat	5.25	
	6	Wheat	60	80
		Berseem	3	3
EL-Sebakhat	1	Wheat	25	30
		Berseem	5	22.5
		Onion		
	2	Wheat	8.75	350
		Berseem	50	12
	3	Wheat	10.125	125
		Berseem		5.625
	4	Wheat	15.75	112.5
		Berseem	290.25	22.5
	5	Wheat	18.75	160
		Berseem	500	4.5
		Sugar beet	37.5	
Out of area served	1	Berseem		280
		Wheat	4.5	
	2	Berseem	218.75	162.5
	3	Wheat		187.5
		Berseem	110	
	4	Wheat	8.5	10.5
	5	Wheat	1.325	9.375
		Berseem	75	1.25

Source: Collected and calculated from the multidisciplinary survey.

Table 2.10. Total summer production for the three groups.

Group	Production of rice (t/ha)			Production of cotton (t/ha)		
	2004	2005	2006	2004	2005	2006
El Talamza						
1	20	35	40	0.89	2.2	1.5
2	6	6.5	4.5		0.94	1.3
3	3	3	4.3			
4	30	32	33			
5	6.5	7	3.5			1.2
6	6	6.5	5.5			
El Sebakhat						
1	15	20.5	25	3.14	5.7	1.9
2	7	8	8	0.9	0.9	1.2
3		15	4	2.8	1.9	1.3
4	18	20	22	2.4	2.9	1.6
5	16	20	20	2	2.8	4.9
Out of area served						
1	10	10.5	10.5			
2	6.5	7	16			
3	6.5	7.5	10			
4	7	7	8			
5	2.5	2.5	3			

Source: Collected and calculated from the multidisciplinary survey.

2.4 Results

2.4.1 Wheat

Results in Tables 2.12 and 2.13 indicate that deficit irrigation reduced the amounts of irrigation water by between 145mm and 58 mm (between 25% and 19%) in 2005-2006 and between 174 mm and 92 mm (between 21% and 29%) in 2006-2007. Over all, the average amounts of water saved were 107 mm (22%) in 2005-2006 and 137 mm, (24%) in 2006-2007.

At four of the six farms, deficit irrigation under basin conditions resulted in a significant reduction in the wheat yield in 2006-2007 as shown in Tables 2.12, 2.13, and 2.14. However, the yield reductions were much less than the amounts of water saved in the two seasons. Yield reductions ranged from 2% to 8% in 2005-2006 and from 2% to11% in 2006-2007 while the amounts of water saved ranged from 19% to 25% in 2005-2006 and from 21% to 27% in 2006-2007. The reductions in the yields depended on the farmers' management practices. Deficit irrigation resulted in a lower grain yield than the farmers' irrigation practices. In 2005-2006 the yields were less by between 100 kg/ha (2%) and 152 kg/ha (8%) and in 2006-2007 they were down by between 117 kg/ha (2%) and 790 kg/ha (11%) for the farms on these marginal lands.

Table 2.11. Productivity of main crops in El-Serw area.

Crop	El-Talamza	El-Sebakhat	Out of area served
Winter season crops			
Wheat (t/ha)	5.8	7.0	7.0
Berseem (t/ha)	37.5	32.5	37.5
Sugar beet (t/ha)			50
Summer season crops			
Cotton (t/ha)	2.0	3.2	2.8
Rice (t/ha)	7.5	10	8.8

Source: Collected and calculated from the multidisciplinary survey.

Table 2.12. Effect of different water regimes on the yield of wheat on marginal lands at El-Serw, 2005-2006 and 2006-2007 seasons.

	Talamza		Sebakhat		Out of area served	
Farm	1	2	3	4	5	6
			2005-2006 Amount of water applied (mm)			
Farmer practice	595	587	590	592	297	304
Req	558	547	539	534	282	291
0.7 req	463	455	449	447	233	246
			2006-2007 Amount of water applied (mm)			
Farmer practice	646	643	723	607	450	345
Req	613	605	679	505	430	311
0.7 req	512	504	554	433	336	253
W.F$_b$	536	533	584	450	368	275
			2005-2006 Yield (t/ha)			
Farmer practice	5.60	5.25	4.55	6.20	4.52	3.35
Req	5.56	5.30	4.60	6.25	4.53	3.40
0.7 req	5.50	5.15	4.40	5.70	4.15	3.30
Aver	5.55	5.23	4.52	6.05	4.40	3.35
			2006-2007 Yield)t/ha)			
Farmer practice	$6.02^{(a)}$	6.70^{a}	6.25^{b}	7.19^{b}	5.60^{b}	5.45^{b}
Req	6.62^{b}	7.12^{b}	6.79^{c}	8.38^{c}	6.18^{c}	6.24^{c}
0.7 req	5.90^{a}	6.40^{a}	5.81^{a}	6.40^{a}	5.05^{a}	4.85^{a}
W.F$_b$	6.61^{b}	7.20^{b}	7.27^{d}	8.03^{c}	5.93^{bc}	5.99^{c}

Note: +$^{(a,b,cd)}$: Numbers followed by the same letter are not statistically different at a < 5%.

Table 2.13. Effect of interventions on WP for wheat in kg/m^3 at El-Serw in the 2005-2006 and 2006-2007 seasons.

	El-Talmza		Sebakhat		Out of area served	
	Hassan	**Hamdy**	**El-Bon**	**Mohamdein**	**El-Sayed**	**El-Morsy**
			2005-2006			
Farmer practice	0.94	0.89	0.77	1.05	1.52	1.1
Req	1.00	0.97	0.85	1.17	1.61	1.17
0.7 req	1.19	1.13	0.98	1.28	1.78	1.34
			2006-2007			
Farmer practice	0.93	1.04	0.87	1.19	1.24	1.58
Req	1.08	1.18	1.00	1.66	1.44	2.01
0.7 req	1.15	1.27	1.05	1.48	1.50	1.92
Water productivity (kg/m^3)	1.23	1.35	1.25	1.78	1.61	2.18

Note: Req – irrigation water requirements.

Table 2.14. Average amount of water applied, yield, and WP for wheat at El-Serw for the 2005-2006 and 2006-2007 seasons.

	Farmer practice	Req	0.7 req	W.F$_h$
Water applied (mm)	558	503.4	394	438.8
Yield (t/ha)	5.556	5.915	5.217	6.839
WP (kg/m^3)	1.091	1.261	1.364	1.567
Relative amount of water applied	1	0.90	0.71	0.79
Relative yield	1	1.06	0.94	1.23
Relative WP	1	1.16	1.16	1.44

Note: Req – irrigation water requirements.

In the experiment, deficit irrigation resulted in an increase in WP by between 0.22 kg/m^3 (17%) and 0.24 kg/m^3 (25 %) in 2005-2006. They were also up by between 0.221 kg/m^3 (21%) and 0.339 kg/m^3 (25%) as compared to the yields recorded for the farmers' irrigation practices in 2006-2007. Generally, the WP was 1.115 kg/m^3 for the farmers' irrigation practices and 1.333 kg/m^3 for deficit irrigation practices in 2005-2006 and between 1.141 kg/m^3 for the farmers' irrigation practices and 1.395 kg/m^3 for the deficit irrigation practices in 2006.

The irrigation water requirement saved 55 mm (10%), increased the yield by 6 %, and the WP by 0.170 kg/m^3 (16%) over the comparable results using the farmers' usual irrigation practices. The deficit irrigation practice increased WP by 25%.

In conclusion, deficit irrigation yield of 239 kg/ha represented a yield reduction of about 6%. This was achieved with a 29% (162 mm) saving in irrigation water and resulted in improving WP by 0.273kg/m^3 as compared to farmers' irrigation practices.

Traditionally, at El-Serw site, wheat is not grown in narrow raised seed beds, but is cultivated as a broadcast crop in the basin. Tables 2.12 and 2.14 and Figure 2.2 show the effects (RBb) of the irrigation water interventions used on grain yield and water productivity (WP). The amount of water saved compared to the farmers' traditional management practices (growing wheat in the basin as a broadcast crop) ranged from 72 mm to 157mm. The amount of irrigation water saved varied between 157 mm (26%) and 72 mm (17%) as compared to amount used in the farmers' traditional practices. Overall, the amount of irrigation water saved was 111 mm, which represents a saving on the amount used in the farmers' traditional practices of about 20%.

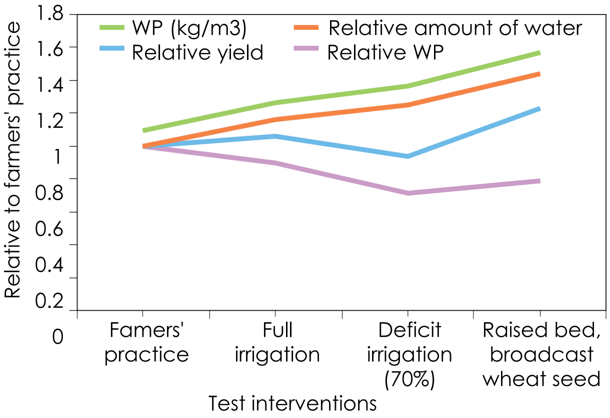

Figure 2.2. Average WP, relative amount of water, relative yield and relative WP of wheat at El-Serw site for the 2005-2006 and 2006-2007 seasons.

Besides reducing the amount of water that needs to be applied by the farmers, the broadcasting seed on a raised-seed bed method significantly increased wheat grain yield – by between about 8% and

16% (between 509 kg/ha and 1018 kg/ha) – over that produced by the farmers' irrigation practices. The average increase in wheat grain yield over the farmers' irrigation practices was 639 kg/ha (10%). See Table 2.12.

The use of wide raised seed beds reduced the amount of water that needed to be applied by the farmer and increased the yield, leading to higher water productivity. In the 2006-2007 season, the water productivities for wheat grown by broadcasting seed on wide raised beds was as shown in Table 2.14. These results can be compared with the WPs achieved using the farmers' traditional irrigation practices which are available above. Over all the farms, the water productivity for the farmers' practices was 1.146 kg/m^3, while that for the wide raised beds was 1.585 kg/m^3 – this represents a nearly 38% increase.

Generally, under salt-affected conditions, planting wheat on wide furrows by broadcasting the seed seems a simple way to save water and increase wheat grain yield. This was reflected in higher water productivity. The raised seed bed saved 119 mm (21%) of the water and increased the yield by 1283 kg/ha (23%), and the water productivity 0.476 kg/m^3 (44%).

2.4.2 Berseem

The data in Table 2.15 illustrate the effects of the interventions on water applied, yield, and water productivity of berseem at El-Serw for 2005-06 and 2006-07.

By comparing deficit irrigation (70% of full irrigation) with the farmers' practices in 2005-2006, it was found that this technique saved at least 52% of the water applied under the farmers' practices. The corresponding reduction in yield ranged from 9% to 19%. The water productivity for the deficit irrigation practice followed by that for the full irrigation treatment showed higher values than that achieved following the farmers' usual practices.

In 2006-2007, deficit irrigation reduced the seasonal amount of water applied by the farmers by 371 mm (a 44% reduction). Figure 2.3 shows that deficit irrigation significantly reduced dry yield by 2.95 t/ha (12%) compared to the yield from the farmers' usual irrigation practices under basin irrigation. However, the reduction in fodder yield is much less than the amount of water saved. Thus, the water productivity of the deficit irrigation was higher by 0.724 kg/m^3 (33%) than that obtained by traditional practices. In comparison to the water requirement of berseem, the farmers applied on average 119 mm (15%) more than was necessary. This increased supply of water resulted in a decrease in yield of between 0.5 t/ha and 2.9 t/ha in 2005-2006 and 2.3 t/ha in 2006-2007. These figures represent an average decrease in 2005-2006 of 6.5% and a decrease of 8 % for the second season. A higher WP was obtained following the deficit irrigation regime, followed by supplying the actual irrigation water requirements.

2.4.3 Cotton

The data for the cotton yield, given in Table 2.16 indicates that the farmers' irrigation practices gave the lowest seed yields. The yield obtained using wide furrow was 173 kg/ha higher than farmers' practices in 2006 and 906 kg/ha more in 2007. The amount of

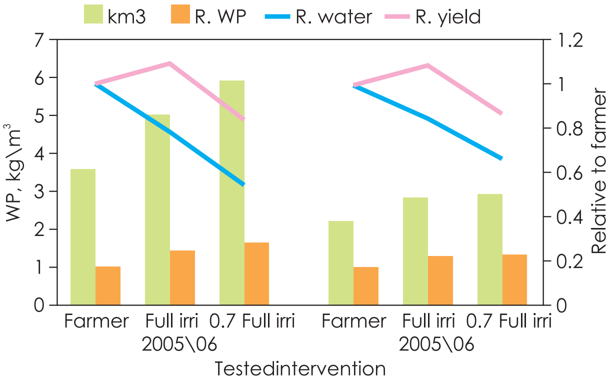

Figure 2.3. Average WP, relative yield, relative amount of water applied, and relative WP of berseem at El-Serw in the 2006 and 2007 seasons.

Table 2.15. Effects of different water treatments on the yield, and WP for berseem at El-Serw for the 2005-2006 and 2006-2007 seasons

Farmer	Treatment	2005-2006			2006-2007		
		Water applied (mm)	Yield (t/ha)	WP (kg/m^3)	Water applied (mm)	Yield (t/ha)	WP (kg/m^3)
Hamdy	Farmer practice	510	23.42	4.592	1,100	24.4^b	2.218
	Req	385	24.11	6.262	929	26.69^c	2.873
	0.7 req	271	21.85	8.062	729	21.45^a	2.942
El-Bon	Farmer practice	540	14.40	2.667			
	Req	375	17.33	4.620			
	0.7 req	263	12.00	4.561			
Khafagy	Farmer practice	450	15.83	3.517			
	Req	384	16.35	4.258			
	0.7 req	268	13.95	5.204			
			Relative				
Hamdy	Farmer practice	100	100	100	100	100	100
	Req	75.49	102.95	136.37	84	109	129
	0.7 req	53.14	93.30	175.57	66	88	133
El-Bon	Farmer practice	100	100	100			
	Req	69.44	120.35	173.23			
	0.7 req	48.70	83.33	171.02			
Khafagy	Farmer practice	100	100	100			
	Req	85.33	103.28	121.07			
	0.7 req	59.56	88.12	147.97			

Table 2.16. Effects of different water management interventions on the yield and WP of cotton on marginal land at El Serw in the 2006 and 2007 seasons.

	2006				2007			
	Farmer practice	Full	0.7 full	WF$_h$	Farmer practice	Full	0.7 full	WF$_h$
Yield (t/ha)	2.365	3.193	2.71	2.538	2.730	3.702	3.825	3.636
Amount of water (mm)	1133	1016	855	854	995	919	745	781
WP (kg/m^3)	0.209	0.314	0.317	0.297	0.274	0.403	0.513	0.466
Relative								
Yield	1	1.350	1.146	1.073	1	1.356	1.4	1.33
Amount of water	1	0.897	0.755	0.754	1	0.92	0.75	0.78
WP	1	1.505	1.518	1.423	1	1.47	1.87	1.70

irrigation water waved by the wide furrow method amounted to 25% (279 mm) in 2006 and 22 % (214 mm) for 2007. For water productivity, the relative increases were from 50 to 58%, being 0.105, 0.207 and 0.088 kg/m for full irrigation, 0.75 of required irrigation and wide irrigation furrow, respectively.

2.4.4 Rice

The effects of different irrigation regimes on the yield of rice grown on marginal lands at El-Serw are shown in Tables 2.17 and 2.18. The data show that using a saturation regime resulted in a lower rice yield as compared to the farmers' usual regime of watering at four or eight day intervals to a 7cm depth. The best results were obtained using irrigation every four days in the two seasons 2006 and 2007.

The relative increases in yield over the farmers' practices ranged from 168 kg/ha (2%) to 855 kg/ha (11%) in 2006 2 and from 325kg/ha (1%) to 1055 kg/ha (7%) in 2007. Also, the four day intervals saved between

Table 2.17 Effects of different water treatments on the yield and WP of rice on marginal lands at El-Serw in the 2006 season.

	Farmer practice	4 day	8 day	Saturation	Aver	Farmer practice	4 day	8 day	Saturation
	Yield (t/ha)					**Relative yield**			
Farm 2 Hassan	6.913	7.688^{i}	6.178^{m}	5.8^{n}	6.645^{e}	1	1.11	0.89	0.84
Farm 3 El Bon	9.08^{cde}	9.388^{b}	8.925^{e}	7.245^{k}	8.66^{b}	1	1.03	0.98	0.8
Farm 4 Mohamde	9.22^{bc}	10.075^{a}	9.235^{bc}	7.79^{hi}	9.08^{a}	1	1.09	1.00	0.84
Farm 5 Sayed	7.893^{h}	8.63^{f}	8.213^{g}	7.25^{k}	7.997^{d}	1	1.09	1.04	0.92
Farm 6 Morsy	8.96^{de}	9.128^{cd}	8.72^{f}	7.443^{j}	8.563^{c}	1	1.02	0.97	0.83
Aver	8.413^{b}	8.982^{a}	8.254^{c}	7.106^{d}	8.189	1	1.07	0.98	0.84
	Amount of water applied (mm)					**Relative amount of water applied**			
Farm 2 Hassan	1500	1350	1100	920	1218	1	0.9	0.73	0.61
Farm 3 El Bon	1400	1300	1150	1000	1213	1	0.93	0.82	0.71
Farm4 Mohamde	1350	1250	1050	910	1140	1	0.93	0.78	0.67
Farm 5 Sayed	1050	950	800	700	875	1	0.9	0.76	0.67
Farm 6 Morsy	1150	1050	900	740	960	1	0.91	0.78	0.64
Aver	1290	1180	1000	854	1081	1	0.91	0.78	0.66
	Water productivity (kg/m³)					**Relative water productivity**			
Farm 2 Hassan	0.461	0.569	0.562	0.63	0.556	1	1.23	1.22	1.37
Farm 3 El Bon	0.649	0.722	0.776	0.725	0.718	1	1.11	1.20	1.12
Farm 4 Mohamde	0.683	0.806	0.88	0.856	0.806	1	1.18	1.29	1.25
Farm 5 Sayed	0.752	0.908	1.027	1.036	0.931	1	1.21	1.37	1.38
Farm 6 Morsy	0.779	0.869	0.969	1.006	0.906	1	1.12	1.24	1.29
Aver	0.665	0.775	0.843	0.851	0.783	1	1.17	1.27	1.28

Note: + $^{(a,b,cd)}$: Numbers followed by the same letter are not statistically different at a < 5%.

Table 2.18. Effects of different water treatments on the yield and WP of rice on marginal land at El-Serw in the 2007 season.

	Farmer practice	4 day	8 day	Satur	Raised bed method	Farmer practice	4 day	8 day	Satur	Raised bed method
			Yield (t/ha)					Relative yield		
1	8.5^{b}	9.09^{bc}	8.223^{b}	6.338^{a}	8.214^{b}	1	1.07	0.97	0.75	0.97
2	8.958^{b}	9.228^{b}	8.768^{b}	6.768^{a}	9.105^{b}	1	1.03	0.98	0.76	1.02
3	8.958^{b}	9.588^{c}	8.525^{b}	7.175^{a}	8.703^{b}	1	1.07	0.95	0.80	0.97
4	8.933^{c}	8.988^{c}	8.26^{b}	7.393^{a}	8.956^{c}	1	1.01	0.92	0.83	1.00
5	8.913^{c}	9.238^{c}	8.705^{b}	8.178^{b}	9.331^{c}	1	1.04	0.98	0.92	1.05
Aver	8.852	9.226	8.496	7.170	8.862	1	1.04	0.96	0.81	1.00
	Amount of water applied (mm)					Relative amount of water applied				
1	1200	1130	1030	760	725	1	0.94	0.86	0.63	0.60
2	1280	1180	1040	780	720	1	0.92	0.81	0.61	0.56
3	1320	1180	1020	840	800	1	0.89	0.77	0.64	0.61
4	1330	1190	1030	840	810	1	0.89	0.77	0.63	0.61
5	1160	1000	850	760	690	1	0.86	0.73	0.66	0.59
Aver	1258	1136	994	796	749	1	0.90	0.79	0.63	0.60
	Water productivity (kg/m^3)					Relative water productivity				
1	0.708	0.804	0.798	0.834	1.133	1	1.14	1.13	1.18	1.60
2	0.7	0.782	0.843	0.868	1.265	1	1.12	1.20	1.24	1.81
3	0.679	0.813	0.836	0.854	1.088	1	1.20	1.23	1.26	1.60
4	0.672	0.755	0.802	0.88	1.106	1	1.12	1.19	1.31	1.65
5	0.768	0.924	1.024	1.076	1.352	1	1.20	1.33	1.40	1.76
Aver	0.705	0.816	0.861	0.902	1.189	1	1.16	1.22	1.28	1.68

Note: + $^{(a,b,cd)}$: Numbers followed by the same letter are not statistically different at a < 5%.

100 mm (18%) and 150 mm (27%) of the irrigation water in 2006 and between 70 mm (6%) and 140 mm (14%) in 2007, in comparison to the farmers' practices.

In 2006, irrigation at eight day intervals reduced the rice yield by between 155 kg/ha (2%) and 735 kg/ha (11%). The amount of water saved compared to the farmers' irrigation practices ranged from 250 mm (18%) and 400 mm (27%). In the 2007 season, irrigating at eight day intervals reduced the yield by between 190 kg/ha (2%) and 673 kg/ha (8%) while the amount of water saved ranged from 170 mm (14%) to 310 mm (27%). The advantage of the water saturation regime is that it saves the most irrigation water. The amount of water saved was not less than 350 mm (27%) and was as high as 580 mm (39%) in 2006 and varied between 442 mm and 500 mm in 2007. In 2006 the reduction in yield ranged from 643 kg/ha (8%) to not more than 1835 kg/ha (20%) while in 2007 the variation was from 735 kg/ha (8%) to2162 kg/ha (25%).

To introduce another simple water saving practice, rice grown on raised seed beds was tested in the second season, 2007 (Table 2.18). When calculated over the actual area sown on the raised bed, this treatment had total grain yields in g/m^2 of 821, 910, 870, 895 and 933 on Farms 1, 2, 3, 4, and 5. These results can be compared to the yields resulting from the farmers' usual irrigation practices of 850, 896, 896, 893 and 891 g/m^2. The amounts of water saved were 475, 560, 520, 470 and 509 mm which are not less than 39% as compared to farmers' practices (Table 2.18).

Tables 2.17 and 2.18 show that the average water productivity values for all the farms were, in ascending order, in 2006, 0.665 kg/m^3 (farmers' usual practices), 0.775 kg/m^3 (four day irrigation cycle), 0.843 kg/m^3 (eight day irrigation cycle), and 0.851 kg/m^3 (saturation treatment). The comparable values in 2007 were 0.705 kg/m^3 (farmers' practices), 0.816 kg/m^3 (four day irrigation cycle), 0.861 kg/m^3 (eight day irrigation cycle), 0.902 kg/m^3 (saturation treatment), and 0.923 kg/m^3 (raised bed method).

It can be seen, that the saturation treatment produced higher water productivity compared to the four and eight day irrigation cycles and the farmers' treatments. However, it is practically difficult for the farmers to adopt this finding. This raised seed bed method for rice cultivation was tested in the 2007 season as a modified cultural practice. The results pointed out that it is a promising practice if it is well implemented, for increasing rice water productivity, while maintaining acceptable yield levels. Consequently, growing rice on raised seed beds was carried out during the 2008 season in marginal land sites with certain modifications to improve the technology.

2.5 Conclusions

- The results of the on-farm trials showed that recommended irrigation techniques are simple techniques that can be easily implemented by the farmers. They can lead to a significant increase in the yield, crop water productivity, and in the amounts of water saved as compared with those obtained following the farmers' traditional practices.
- Deficit irrigation is a technique that has shown a beneficial effect in maximizing crop water productivity. The results of the trials carried showed that the implementation of such a technique, where a relatively high proportion of the irrigation water is saved, did not result in any significant losses in yield for the major crops.
- The raised bed technique showed very satisfactory results on the different sites investigated (old lands and marginal lands) with the main winter (wheat and berseem) and summer (corn and cotton) crops. This technique, besides saving around 30% of the amount of water applied, increased crop production by nearly 10% over the farmers' traditional irrigation practices. Furthermore, the implementation of such a simple technique resulted in average water saving amounting to between 20% and 25% of that corresponding to the basin irrigation practice of the farmers.
- When the crop was irrigated with 70% of the required amount of water, the reduction in wheat yield compared to that obtained under full irrigation was only 8%. This, again, confirms that we can produce nearly the same yield, while saving up to 30% of the water traditionally applied by farmers.
- Cotton could be produced successfully by reducing the volume of irrigation water applied. Irrigation of cotton with volumes of water corresponding to 70% of the required amount resulted in a yield reduction corresponding to 10% of the yield obtained under the farmer's irrigation practices.

Chapter 3: Enhancing soil fertility and irrigation management in the new lands

Chapter 3: Enhancing soil fertility and irrigation management in the new lands

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3.1 Characteristics of the new lands

3.1.1 El-Bustan site

The selected site, El-Husain village, is located in Behaira Governorate in North Delta as shown in Figure 3.1. It is situated about 45 km east of the Alexandria desert road and south of Nubaria canal on branches No. 5 and 12. It was selected purposely to represent the particular community and serves an area of about 100 feddan. The mesqa is still under improvement.

The new lands are represented by the El-Bustan area. The soils of the site are mostly sandy with low fertility and relatively low water holding capacity and crops are grown exclusively under irrigation using modern irrigation systems.

The site has the general characteristics of the new lands:

Figure 3.1. The new lands site location at El-Bustan.

- No fixed cropping pattern
- Shortage of irrigation water, especially in summer
- Availability of improved irrigation systems (drip irrigation and sprinkler irrigation)
- After agricultural liberalization, the cropping pattern has changed gradually towards the production of vegetables at the expense of field crops.

El-Bustan 2 secondary canal, which supports improved irrigation systems, was selected as the community for study (irrigation branch 5). This canal passes across five villages, Abd El Monem Riad, El Ghazaly, El Husain, Mohamed Refaat, and Ahmed Ramy. It serves about 25,000 feddan. There are 16 mesqas (branches) along this canal, serving the five villages.

3.1.2 Soil characteristics

The physical and chemical characteristics of the soil and the N, P, and K content are presented in Table 3.1 for the El-Monofia, El-Serw, and El-Bustan sites.

The analysis of the soils of the new lands El-Bustan site shows that they are sandy with the sand fraction corresponding to nearly 90% of the soils' mechanical separates. However, compared to the other soils investigated in the other sites, they have the lowest EC value – not exceeding 0.3 dS/m. Furthermore, the soils corresponding to this site are the poorest in their nutrient contents, especially potassium, when compared with those of both the Monofia and El-Serw sites.

Agricultural practices in the newly reclaimed lands (known as new lands)

Table 3.1. Fertility and physical and chemical analyses of the soils of the new lands (El Bustan).

Farm no.	N (ppm)	P (ppm)	K (ppm)	Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)	$CaCO_3$ (%)	EC (dS/m)	pH (1:2.5)
With water users associations										
1	45	11.7	50	66.8	25.5	1.55	6.15	4.8	0.29	7.87
2	15	14.82	35	69.4	22.5	1.74	6.36	5.1	0.28	7.7
Without water users associations										
3	35	40.56	50	58.5	35.6	1.25	4.65	4.6	0.27	7.95
4	60	11.7	70	76.2	16.6	1.45	5.75	5.0	0.3	8.04

differ from those of the old lands. In the new lands, most farmers grow fruit trees on half their areas. The farmers select their cropping patterns according to labor availability and the profitability of the cultivated crops.

In these lands, farmers are not aware of water productivity or its return. Therefore, this study focused on the importance of these criteria besides clarifying the role of the water users associations (WUAs) in solving water problems as well.

3.1.3 Farmer selection procedures

Twenty-nine farmers were interviewed (8% of the total farmer population live in the village) and they are spatially distributed as follows:

- 17 farmers are members in the WUA area
- 12 farmers live in an area without a water users association (No WUA).

Superimposed on this spatial stratification, 41% of the sample is made up of university graduates who live in the No WUA area while the rest (59%) are members of the WUA area. We also worked on two separate irrigation groups, surveying farmers from the heads to the ends of the irrigation canals, to have a third criterion of differentiation based on water supply.

The farmers were partitioned into two different groups located across the Nubaria canal. Two basins were selected (referred to as groups). The first group was labeled WUA, and included farms irrigated according to the WUA basis. The second group, labeled No WUA, involved farms which have no WUA and work illegally.

A sample of 10 farmers was selected to monitor the biophysical and socioeconomic parameters. The selected farmers were interviewed twice a year. Table 3.2 shows a breakdown of the sample according to the type of group and the gender divisions within each group.

Table 3.2. Group membership and gender of the selected farmers.

Group	Men	Women	Total
WUA	4	1	5
No WUA	5	0	5
Total	9	1	10

Source: Collected and calculated from the multidisciplinary survey

3.1.4 Characteristics of the community

All the farmers in El-Husain village settled there at almost the same time in 1988-1989. The earliest arrivals were in 1988 and the latest in 1989. Moreover, all the farmers are university graduates.

3.1.5 Farm size

There is no variation in farm size among the farmers in the two groups because each graduate has settled 5 feddan according to the law of land settlements. Thus, all graduates in both groups approximately own the same area (2.1 ha), but some of them rent out their lands to beneficiaries or graduates and prefer to return to their original place; although they are still legally tied to their land.

3.1.6 Family size and workforce

All the families are nearly the same size; but the family workforces differ between the two groups. Thus, the total family labor is estimated at 16 HLU in the WUA group and 12 HLU in the No WUA group. This difference arises from the high variability of the cropping patterns in the two categories. Most WUA farmers grow tree fruits, which need less labor than vegetable and field crops.

3.1.7 Structural ratios

The average amount of land available per family member (cultivated area by human consumption unit, or CA/HCU) is also almost the same for the graduates – 0.3 ha in the WUA group versus 0.35 ha in No WUA group. The average family labor available per hectare (HLU/CA) is less 0.45 for the WUA graduates as compared to 0.48 in the No WUA group. Therefore, there is a greater need for hired labor in the No WUA group.

3.1.8 Livestock holding

Of the farmers, 28% have animals while the remaining 72% do not have or are not interested in animal production. Graduates who have animals usually lend them to beneficiaries or other graduates under a sharing system – the animal and half of the off-spring belongs to the owner. The other farmer is totally responsible for feeding and tending the animals, and receives animal products in exchange, plus keeps half the off-spring. All graduates have slightly larger livestock holdings, but variability is high. Therefore, this difference is not considered as really significant.

3.1.9 Farmers' incomes

The participating farmers were asked about their present and future plans for purchasing, constructing, or expanding their new lands holdings, buying trucks, buildings, or any other investments during the last year which affected the farmers' capability to save and invest. Table 3.3 shows that not all the farmers invested part of their agricultural income, but most farmers were willing to invest for the future.

Table 3.4 shows that farmers in El-Bustan area consider wheat as their main source of agricultural income in winter. This is supplemented by the income from their fruit trees. There is high variation in the total

Table 3.3. Current and future investments of the farmers.

Farmer code	Current investment	Future investment
1	-	Expanding building a house
2	-	Expanding building a house
3	Building a house	Building a store
4	-	Buying a tractor
5	-	Establishing a greenhouse
6	Complete building a house	Buying a car to manage the farm
7	Complete building a house	
8	Complete building a house	
9	Complete building a house	Buying a truck
10	Complete building a house	Buying a truck for marketing crops

Source: Monitoring and Evaluation (M&E) Survey Report, 2006.

income earned from crop sales, ranging between EGP 1250 and EGP 7900.

In the summer the income from the fruit trees supplements that from peanuts, the main source of income in this period. Table 3.5 shows the variation in total income earned from crop sales. This ranged between EGP 3380 and EGP 10,500. It can be seen that the WUA group farmers earned higher incomes from horticultural crops (24%) than their No WUA counterparts, while the No WUA farmers earned higher incomes from field crops (87.5%) than those of the WUA group.

Table 3.6 gives an overview of the main descriptors used in characterizing the samples.

Table 3.4. Income earned in the winter from different activities for the two groups (EGP).

Farmers code no.	Wheat	Faba bean	Peas	Berseem	Potatoes	Total
WUA						
1	4,900	3,000				7,900
2	5,200					5,200
3	7,500					7,500
4	1,400		900	1,400		3,700
5	2,100				4,800	6,900
No WUA						
1	7,500					7,500
2	3,900					3,900
3					3,600	3,600
4*						
5		1,250				1,250

Note: * Farmer no. 4 did not plant any field crops and substituted these with fruit trees.
Source: M&E Survey of winter 2006.

Table 3.5. Income earned in the summer from different activities for the two groups (EGP).

Farmer code no.	Peanut	Maize	Watermelon seeds	Guava	Green beans	Total
WUA						
1	5,000	1,000	800			6,800
2	6,300					6,300
3	7,500					7,500
4	1,400	1,980				3,380
5	2,520				1,120	3,640
No WUA						
1	6,825					6,825
2	5,250					5,250
3	1,680	4,050		2,500		8,230
4*						
5	10,500					10,500

Note: * Farmer no. 4 did not plant any field crops and substituted these with fruit trees.
Source: M&E Survey of summer 2006.

Table 3.6. Average values of the structural descriptors for the two groups.

Criterion	WUA	NWUA	Whole sample
Median age (years)	40	42	41
Years of settlement	17	17	17
Family size (HCU)	7	6	7
Family workforce (HLU)	16	12	14
Total farm area (feddan)	85	60	145
Farmland use (feddan)	85	60	145
Share of different treatments (feddan)			
Fallow		12	
Trees	12.5	20	
Crops	72.5	28	
Animal holders (%)	30	26	28
Average livestock holding (LU)	3	3	3
Structural ratios			
CA/HCU	0.3	0.35	
HLU/CA	0.45	0.48	

Note: HCU – human consumption unit; HLU – human labor unit; LU– livestock unit; CA – cultivated area.
1 feddan = 0.42 ha.
Source: Collected and calculated from the multidisciplinary survey.

3.1.10 Cropping patterns

Table 3.7 shows that most farmers in El-Bustan plant half of their holding area to fruit trees because of the shortage of labor. Maize and peanut are the main crops in summer and wheat and berseem are the main crops in winter for the two groups. Table 3.8 illustrates the main crop rotations for the two groups.

3.1.11 Area under production

Table 3.9 displays some economic indicators of the winter crops and Table 3.10 shows some economic indicators of the summer crops for the two groups.

Table 3.7. Cropping patterns for the two groups.

Group	Summer 2006	Winter 2006-2007
WUA	Maize, potatoes, peanut,	Wheat, berseem, faba bean, beans
No WUA	Peanut, maize,	Wheat, berseem,

Source: Collected and calculated from the multidisciplinary survey.

3.1.12 Farm budget

Tables 3.11, 3.12, and 3.13 illustrate some economic indicators for peanut, maize, and green beans crops, respectively, for the two groups.

Table 3.14 shows such economic indicators as total cost, total revenue, net return or benefit, and the benefit-cost ratio. These

Table 3.8. The crop rotations for the two groups and the number of farmers for each rotation.

Rotation	WUA	N0 WUA
Potato + peanut	5	4
Potato + potato	2	1
Potato + maize	4	3
Wheat+ maize	2	1
Wheat+ melon	2	0
Wheat + peanut	1	4
Faba bean + maize	1	3
Berseem + maize	2	1

Source: Collected and calculated from the multidisciplinary survey.

Table 3.9. Area (ha) under production for the two groups in winter.

Potato 2006	Potato 2005	Peas 2006	Berseem 2006	Berseem 2005	Faba bean 2006	Wheat 2006	Wheat 2005	Farm code no.
WUA:								
	1				0.6	1		1
						1.2	1	2
	1.2						2	3
	1.6	0.2	0.2	0.2	0.4	0.4		4
0.4	1					0.4		5
No WUA:								
	1					1.2		1
				1		0.6	1	2
1.6	1.6							3
								4*
	2				2			5

Note: * Farmer no. 4 did not plant any field crops and substituted these with fruit trees.
Source: M&E Survey of winter 2006.

Table 3.10. Area (ha) under production for the two groups in summer.

Peanut			Maize			Group
2006	2005	2004	2006	2005	2004	
WUA						
0.8	1	1	0.5	1		1
1						2
1.2	1.2	1			0.8	3
0.4	0.4	1.4	0.6	0.6	0.2	4
0.4	0.8	0.5			0.5	5
No WUA						
1				1	1	1
0.8	0.8	1				2
0.4	1.6		1.2			3
						4*
2	2					5

Note: * Farmer no. 4 did not plant any field crops and substituted these with fruit trees.
Source: M&E Survey of summer 2006.

indicators differ for the WUA and No WUA groups and among their crops, except for the berseem crop, where the benefit-cost ratio is higher for the WUA group than the No WUA group. The difference is higher in the case of wheat because of the lower benefit to the No WUA group. Berseem has the highest benefit-cost ratio (0.33) for the WUA group compared to 0.55 for the No WUA group. This is a consequence of its price and its importance as animal fodder.

3.1.13 Crop varieties

The different varieties planted by the two groups were, for wheat, Sakha 93 and Sakha 68, for maize, Hybrid 1 and Single Hybrid 310, and Sponta for potato.

3.1.14 Soil and nutrient improvement practices

The two groups use manure and chemical fertilizers. The WUA group has no manure and buys it from the market. However, the

Table 3.11. Some economic indicators of peanut for the two groups

Group	WUA					No WUA			
Code	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**5**
TV cost (EGP)	1,534	1,028	1,210	1,190	1,750	1,798	1,142	1,245	1,145
G. margin (EGP)	2,500	2,520	3,000	1,680	2,520	2,730	2,625	1,680	2,100
Net return (EGP)	966	1,492	1,790	490	770	932	1,483	435	955
B/C ratio	0.63	1.45	1.48	0.41	0.44	0.52	1.30	0.35	0.83
BE price (EGP)	1,918	1,028	1,345	1,983	1,944	1,854	1,446	2,371	1,527
BE yield	0.58	0.37	0.36	0.51	0.63	0.64	0.34	0.39	0.41

Note: TV. cost – total variable cost; G. margin – gross margin; B/C ratio – benefit to cost ratio; BE price – break even price; BE yield – break even yield.
Source: M&E Survey of summer 2006.

Table 3.12. Some economic indicators of maize for the two groups.

Group	WUA		No WUA
Farmer code no.	1	4	3
TV cost	1,303	813	1,195
Gross margin	1,760	1,320	1,350
Net return	4,57	507	155
B/C ratio	0.35	0.62	0.13
BE price (EGP)	1,086	397	569
BE yield	1.95	1.26	1.86

Source: M&E Survey of summer 2006.

Table 3.13. Some economic indicators of green beans for the two groups.

Group	WUA
Farmer code no.	5
TV cost	729
Gross margin	1120
Net return	391.00
B/C ratio	0.54
BE price (EGP)	521
BE yield	0.23

Source: M&E Survey of summer 2006.

Table 3.14. Some economic indicators of wheat for the two groups.

Crop	Wheat		Berseem		Potato		Faba bean	
Item	WUA	No WUA	WUA	No WUA	WUA	No WUA	WUA	No WUA
Total cost	5,683	5,761	2,921	2,700	21,946	17,589	1,819	1,415
Total revenue	7,057	6,042	3,875	3,588	23,973	18,656	2,000	1,249
Benefit	1,374	281	955	1,588	2,026	1,067	181	121
B/C ratio	0.24	0.05	0.33	0.55	0.09	0.06	0.10	0.09

Source: M&E Survey.

No WUA group has manure and uses a greater quantity compared to the WUA group. Thus, the cost of manure is higher for the WUA group. The two groups apply the same quantities of ammonium fertilizer, but the second group applies more ammonium sulfate and mono superphosphate (15.5%). However, the No WUA group applies more potassium sulfate as shown in Table 3.15.

Table 3.15. Quantity of fertilizer applied (per ha) for the two groups.

Item	WUA	No WUA
Manure:		
Available	No	Yes
Application	Yes	Yes
Quantity (m^3)	25	37.5
Price (EGP/m^3)	150	62.5
Leaf fertilizer:		
Application	Yes	Yes
Chemical fertilizer (50 kg bag):		
Urea 46.5%		
Ammonium nitrate 33.5%	25	25
Ammonium sulfate 20%		4
Mono superphosphate 15.5%	7.5	10
Potassium 48%	5	1.25

Source: Checklist of Participatory Rural Appraisal.

There are many treatments to maintain good quality soil. No farmer in either of the groups has salinity problems on their lands. In general, there is no drainage system in El-Bustan area, whether open or subsurface. However, this is not considered a problem in sandy soils. Thus, the absence of drainage and its commonly related consequences (high water table, water-logging, and salinity) is a major issue for some farmers having their fields in depressions; it is even more of a problem if they are located close to major canals. To maintain soil fertility, all farmers add manure and chemical fertilizers.

3.1.15 Water management and supply

Farms situated far from the line heads of three irrigation lines were surveyed to investigate water supply variations among the farmers in El-Bustan village depending on the distances between their fields and the main canal. The irrigation water is fresh and of good quality. Fresh water is mixed with drainage water in June and July, but the quality remains good, in general

The farmers were grouped into three classes based on the distances of their fields from the line head – beginning class (0 to 300 m), middle class (300 to 900 m), and tail class (900 to 2000 m). The maximum distance from the line head was assumed to be 2 km and the minimum distance was 5 m. Each class contained 10 farmers.

The survey showed that there was no significant difference in water supply between those farmers located close to the head of the irrigation line and those located at the end, especially in the WUA group. Problems of low pressure are common at the end of the line, especially if there is a slope between the head and the tail. However, the water supply is not really a criterion for differentiation between farmers, especially regarding the cropping pattern and rotations they practice.

The majority of farmers use moving sprinklers. However, some farmers changed to a fixed irrigation system using drippers. The average number of irrigations and the hours/mohaya irrigation for each crop are listed in Table 3.16. As can be seen from the Table there is considerable variation between the two groups (WUA and NWUA) for the potato and berseem crops, especially regarding the number of irrigations. This is one positive outcome of the WUA on water availability (quantity and quality).

Table 3.16. Length of time (hour/ha) and number of irrigations for the two groups.

Item	WUA		NWUA	
	Mohaya (hr/ha)	No of irrigations	*Mohaya* (hr/ha)	No of irrigations
Potato	3	40	3	30
Wheat	2	30	2.5	30
Faba bean	1.5	25	2	25
Berseem	3	50	3	25

Note: Mohaya – first, post-planting irrigation.

Source: Collected and calculated from the multidisciplinary survey.

Farmers in the two groups do not experience water table problems during most months of the year except June and July. The farmers in the WUA group solve these problems by allocating the irrigation time among themselves. Of the farmers in the NWUA group, those at the end of the canal experience some problems, but they are not unduly negatively affected because they try to solve these problems in a manner similar to the farmers in the WUA.

3.1.16 Irrigation costs

Table 3.17 shows that the total irrigation costs of the WUA group are less than those of the NWUA one. These reduced costs arise from the use of regular irrigation water and the shorter irrigation times, and they demonstrate the positive influence of the WUA on irrigation costs.

Water shortages may occur in April, August, and September, affecting the productivity of some crops, such as wheat, peanut, maize, and fruit trees.

3.1.17 Pest and weed control

Weeds are found in the lands of both groups. Manure and water are the main sources for these infestations. Farmers apply both manual and chemical controls. Nematodes and berseem and bean dodders are the main plant pests for the two groups. They also resort to manual and chemical pest control to deal with these.

Table 3.17. Irrigation costs of the main crops for the two groups.

Crop	NWUA				WUA			
	No of irri.	hr/ha.	EGP/hr	Total cost (EGP/ha)	No of irri.	hr/ha.	EGP/hr	Total cost (EGP/ha)
Winter crops								
Wheat	30	5	2.5	375	17	7	2.5	159
Potatoes	20	5	2.5	250	12	7.5	2.5	225
Faba bean	25	5	2.5	312.5	15	4	2.5	141
Summer crops								
Peanut	30	5	2.5	375	16	7.5	2.5	300
Maize	35	5	2.5	437.5	20	7.5	2.5	375
Potatoes	25	5	2.5	312.5	20	7.5	2.5	375

Source: Collected and calculated from the multidisciplinary survey.

3.1.18 Land productivity

Total production was recorded to compare the positive or negative impacts of the project. Total production is equal to the yield per unit area multiplied by the associated area planted. So, while it is not valid to compare the total production between the two groups, it is useful to use this production divided by the water requirement to reflect water productivity. Tables 3.18 and 3.19 show the total production in the winter and summer seasons for the two groups.

Table 3.20 shows the productivity of the two groups compared to other sites located at Nubaria. It can be seen that the productivity of wheat and maize are smaller than at the Nubaria sites. Moreover, the productivity of the NWUA group is higher than that of the WUA group except for watermelon seeds and maize. The productivity of summer potato is the same for the two groups.

3.2 Objectives and methodologies

3.2.1 New lands

a) Winter crops (wheat and faba bean)

- Farmers' irrigation practices
- Full irrigation (ET + 0.2ET for leaching requirements)
- 80% of full irrigation.

b) Summer crops (groundnut)

- Full irrigation (1.2 ET)
- Deficit irrigation (85% of full irrigation)
- Farmers' irrigation practices

Table 3.18. Total production (t/ha) in winter for the two groups.

Potato 2006	Potato 2005	Peas 2006	Berseem 2006	Berseem 2005	Faba bean 2006	Wheat 2006	Wheat 2005	Group
WUA								
	75				5.6	12.5		1
						12.75	10.3	2
	75					18.75		3
	135	2.5	15	15	5.7	3.5		4
15	75					5.25		5
NWUA								
	112.5					18.8		1
				37.5		6.5	10.3	2
100	80				-			3
					-			4*
	125				19.5			5

Note: * Farmer no. 4 did not plant any field crops and substituted them with fruit trees.

Source: Collected and calculated from the multidisciplinary survey.

Table 3.19. Total production (t/ha) in summer for the two groups.

Peanut 2006	Peanut 2005	Peanut 2004	Maize 2006	Maize 2005	Maize 2004	Group
WUA						
4.7	5.6	4.7	5.5	10.5		1
5.6						2
6.8	5.3	5.0			3.8	3
1.5	2.6	10.0	7.7	7.0	2.5	4
2.3	4.7	7.5			5	5
NWUA						
6.1				15	12.5	1
3.9	4.7	6.8				2
1.3	7.0	-	15.8			3
	4.4	7.0		8.8	9.4	4*
9.4	13.1					5

Note: * Farmer no. 4 did not plant any field crops and substituted them with fruit trees.

Source: Collected and Calculated from the Multidisciplinary survey.

Table 3.20. Productivity (t/ha) of the main crops in El-Husain village.

Crop	WUA	NWUA	Nubaria
Winter season crops			
Wheat	4.5	4.9	6.0
Winter potatoes	30.0	32.5	
Faba bean	3.5	3.9	3.9
Summer season crops			
Peanut	2.25	2.8125	3.3
Water melon seeds	0.75	0.5	1.7
Maize	5.95	3.5	9.4
Summer potatoes	42.5	42.5	26.6
Green beans	3.125		6.6

Source: Productivity of the two groups is collected and calculated from the multidisciplinary survey Productivity at the Nubaria sites was collected from the Agricultural Economics magazine, Ministry of Agriculture.

3.3 Results

3.3.1 Wheat

The data for yield and water productivity are shown in Tables 3.21 and 3.22. Compared to the farmers' irrigation practices, deficit irrigation saved on irrigation water by about 113 mm (26%), 75 mm (18%), 98mm (23%), and 85 mm, (23%) in the 2005-2006 season for Farms 1, 2, 3, and 4, respectively. In the 2006-2007 seasons, the amounts of water saved by the same four farms were 97 mm (27%), 132 mm (31%), 133 mm (30%), and 116 mm (28%).

In 2005-2006 there were not significant reductions in the wheat yields of 36 kg/ha (1%) for Farm 2 and 215 kg/ha (5%) for Farm 4 while Farm 3 showed an increase of 324 kg/ha (5%).. In 2006-2007 the reductions in were 127 kg/ha (3%) for Farm 1, 109 kg/ha (2%) for Farm 2, 46 kg/ha (1%) for Farm 3, and 126 kg/ha (6%) for Farm 4.

Table 3.21. Quantity of water used, yield, and WP for the winter wheat crop (new lands, 2005-2006 and 2006-2007) at El-Bustan site.

	2005-2006 season						2006-2007 season					
	Yield (t/ha)	Amt of water (mm)	WP (kg/m³)	Yield (t/ha.)	Amt of water (mm)	WP (kg/m³)	Yield (t/ha)	Amt of water (mm)	WP (kg/m³)	Yield (t/ha.)	Amt of water (mm)	WP (kg/m³)
	Farm 1			Farm 3			Farm 1			Farm 3		
Farmer practice				5.786	425	1.36	4.663	400	1.165	5.545	435	1.273
Req				6.75	428	1.58	4.46	366	1.219	5.418	362	1.497
80% full irri.				6.11	351	1.74	4.536	296	1.532	5.499	303	1.815
	Farm 2			Farm 4			Farm 2			Farm 4		
Farmer practice	3.893	424	0.92	3.929	414	0.95	5.544	427	1.297	2.142	422	0.507
Full irri.	4.214	387	1.09	3.75	388	0.97	5.544	358	1.549	2.016	365	0.552
80% full irri.	3.857	311	1.24	3.714	316	1.21	5.435	295	1.842	2.016	306	0.659
	NS			NS			NS			Ns		

Note: NS – not significant.

Table 3.22. Average values for the yield, relative yield, amount of irrigation water used, and WP for wheat (new lands, 2005-2006 and 2006-2007) the El-Bustan site.

Irrigation treatment	Yield (t/ha)	Relative yield	Amount of water used (mm)	Relative amount of water used	WP (kg/m³)	Relative WP
2005-2006						
Farmer practice	4.54	1	421	1	1.08	1
Full irri.	4.90	1.08	401	0.95	1.21	1.12
80% full irri.	4.56	1.01	326	0.77	1.38	1.28
2006-2007						
Farmer practice	4.47	1	421	1	1.06	1
Full irri.	4.36	0.98	363	0.86	1.20	1.14
80% full irri.	4.37	0.98	300	0.71	1.46	1.38

It is clear that deficit irrigation resulted in higher water productivity than that obtained from the farmers' irrigation practices (see Tables 3.21 and 3.22). Deficit irrigation yields were 0.32 kg/m^3 (35%), 0.38 kg/m^3 (28%), and 0.22 kg/m^3 (23%) higher than those obtained using the farmers' traditional practices for Farms 2, 3 and 4 respectively in the 2005-2006 season. In the 2006-2007 season, water productivities on Farms 1, 2, 3, and 4 were, respectively, 0.367 kg/m^3 (32%), 0.545 kg/m^3 (42%), 0.542 kg/m^3 (43%), and 0.152 kg/m^3 (30%) higher than those obtained following the farmers' usual practices.

3.3.2 Faba bean

Table 3.23 and Figs 3.2 and 3.3 show the effect of the interventions used on the amount of water saved and the yield produced. There was no significant difference in faba bean yield that could be attributed to irrigation treatments in the 2005-2006 and 2006-2007 seasons. From the first season results it is apparent that the farmers' traditional irrigation practices used 80 mm which is 23% more than used in the deficit irrigation practice. This reduced the faba bean yield by 838 kg/ha (13%). Deficit irrigation saved 97 mm on the amount of water applied by farmer and increased yield by 648 kg/m^3 (11%). Also, the deficit irrigation resulted in higher water productivities. These were 0.800 kg/m^3 (48%)

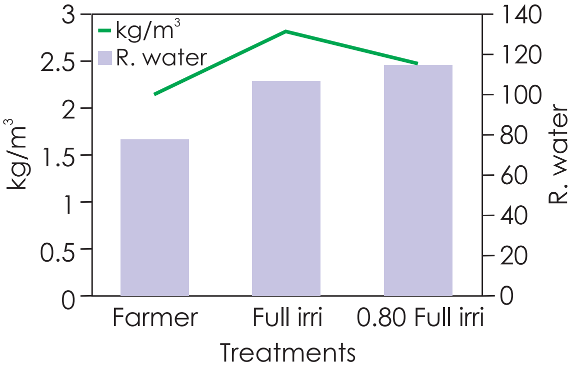

Figure 3.2. Water productivity and relative water productivity for various irrigation treatments of faba bean grown on new land in the 2005-2006 season.

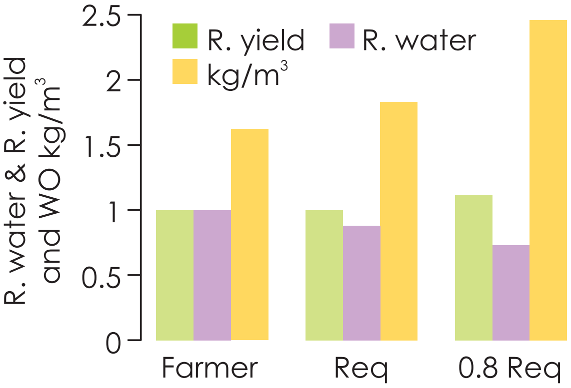

Figure 3.3. Average relative amount of water used, relative yield and WP of faba bean under different irrigation treatments, at El-Bustan in the 2006-2007 season.

Table 3.23. Amount of water used, yield, and WP for the winter faba bean crop (new lands, 2005-2006 and 2006-2007) El-Bustan site.

	2005-06			2006-07		
Irrigation treatment	**Yield (t/ha)**	**Amount of water used (mm)**	**Water productivity (kg/m^3)**	**Yield (t/ha)**	**Amount of water used (mm)**	**Water productivity (kg/m^3)**
Farmer	5.714	347	1.65	5.880	362.8	1.621
Full irri.	7.467	326	2.29	5.880	321	1.830
80% full irri.	6.552	267	2.45	6.528	266	2.450
				NS		

Note: NS – not significant

and 0.829 kg/m^3 (51%) more than that obtained from farmers' irrigation practices for the 2005-2006 and 2006-2007 seasons.

3.3.3 Groundnut

Table 3.24 presents the effects of water interventions on yield and water productivity of groundnut in the new lands for the 2006and 2007 cropping seasons. It was found that irrigating with 85% of the full irrigation requirement produced a higher yield than with the farmers' traditional irrigation practices. The yields for 2006 were 3.4 t/ha under 85% of full irrigation and 3.14 t/ha under the farmers' traditional practices, while in the 2007 the yields were 2.84 t/ha (85% of full irrigation) and 2.97 t/ha (farmers' irrigation practices). The amounts of water saved as compared to the farmers' irrigation practices were 101 mm (18%) in the 2006 season and 72 mm (13%) in the 2007 season. In 2006, the increase in yield attributed to 85% of full irrigation treatment ranged from 0.01 t/ha (8%) to 0.47 t/ha (14%), while the amount of water saved varied between 92

Table 3.24. Effects of different irrigation regimes on the yield and WP of groundnut on new lands in the 2006 and 2007seasons.

	2006						2007					
Farm no.	**FP**	**Req**	**85% of req**	**FP**	**Req**	**85% of req**	**FP**	**Req**	**85% of req**	**FP**	**Req**	**85% of req**
	Yield (t/ha)			**Relative yield**			**Yield (t/ha)**			**Relative yield**		
1	3.14	3.44	3.44	1	1.1	1.1	2.68	3.23	2.85	1	1.21	1.06
2	2.65	2.47	2.66	1	0.93	1	2.72	2.65	2.8	1	0.97	1.03
3	3.42	3.96	3.89	1	1.16	1.14	4.18	4.15	3.64	1	0.99	0.87
4	3.35	3.78	3.62	1	1.05	1.08	2.31	2.37	2.07	1	1.03	0.9
Aver	3.14	3.16	3.40	1	1	1.08	2.973	3.1	2.84	1	1.04	0.96
	Amount of water used (mm)			**Relative amount of water used**			**Amount of water used (mm)**			**Relative amount of water used**		
1	586	545	479	1	0.93	0.82	521	541	462	1	1.04	0.89
2	560	540	468	1	0.96	0.84	588	547	465	1	0.93	0.79
3	620	592	515	1	0.95	0.83	520	570	497	1	1.1	0.96
4	574	551	476	1	0.96	0.83	537	548	455	1	1.02	0.85
Aver	585	557	484.5	1	0.95	0.83	541.5	551.5	469.75	1	1.02	0.87
	Water productivity (kg/m^3)			**Relative water productivity**			**Water productivity (kg/m^3)**			**Relative water productivity**		
1	0.536	0.631	0.718	1	1.18	1.34	0.522	0.49	0.606	1	0.94	1.16
2	0.473	0.457	0.568	1	0.97	1.2	0.463	0.484	0.602	1	1.05	1.3
3	0.552	0.669	0.755	1	1.21	1.37	0.804	0.728	0.732	1	0.91	0.91
4	0.584	0.505	0.761	1	0.86	1.3	0.43	0.432	0.455	1	1.01	1.06
Aver	0.536	0.566	0.701	1	1.06	1.3	0.555	0.534	0.599	1	0.96	1.08

Note: FP – farmer practice; Req – required amount of water.

mm (16%) and 105 mm (18%). In the second season, for Farm 1, the deficit irrigation increased the yield by 80 kg/ha (6%) while saving 59 mm (15%) of irrigation water while for Farm 2 the comparable figures were to 170 kg/ha (3%) and 123 mm (21%).

The average water productivity of the irrigation treatments, for all farms, indicated that full irrigation and 85% of full irrigation improved water productivity. The WP for full irrigation was increased by 6% (0.03 kg/m^3) and that for 85% of full irrigation was increased by 30% (0.165 kg/m^3).

3.4 Conclusions

- The results of the on-farm trials showed that recommended irrigation techniques are simple techniques that can be easily implemented by the farmers. They can lead to a significant increase in the yield, crop water productivity, and in the amounts of water saved as compared with those obtained following the farmers' traditional practices.
- Deficit irrigation is a technique that has shown a beneficial effect in maximizing crop water productivity. The results of the trials carried showed that the implementation of such a technique, where a relatively high proportion of the irrigation water is saved, did not result in any significant losses in yield for the major crops.
- The trials on wheat in the new lands (sandy soils), showed that using 70% of the required amount of water did not affect wheat production at all. The yield losses were only about 2%; but the crop water productivity was significantly increased – it was nearly 38% higher than that obtained under the farmers' usual practices.

Chapter 4: Systems approach to water productivity assessment using cropping system Models

Chapter 4: Systems approach to water productivity assessment using cropping system Models

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4.1 Background and justification

Irrigation management of crops in Egypt is characterized by the application of more water than the crops require. In fact, large amounts of water are supplied without any estimates of the soil water content at the root zone. The rationale for doing so is the assumption that more irrigation water means a greater yield. So, eliminating the use of this unnecessary irrigation water could help save the resource, provided that this can be done with low yield losses. The estimation of soil water reserves in the root zone area is essential for the best irrigation management. This management can be done by modeling water depletion from the root zone under the application of different amounts of irrigation water (Khalil et al., 2007). Models that simulate crop growth and water flow in the root zone can be powerful tools for extrapolating findings and conclusions from field studies to conditions not tested (Smith et al., 2000). Therefore, using these types of models to predict the effect of applying deficit irrigation on the yield of several crops could be an ultimate solution to conserving irrigation water.

Deficit irrigation, while it may result in a yield reduction, in general increases water productivity and has the added benefit that the irrigation water saved can be used in new lands. However, testing these deficit irrigation practices in the field is expensive. Therefore, simulation models could partially substitute for experiments to test different deficit irrigation scenarios and be used to develop recommendations for the conservation of irrigation water and the minimizing of yield losses. Three models were selected for that purpose, CROPWAT, Yield-Stress and CropSyst. Our objective was to use these models to assess the effects of different deficit irrigation scenarios on the yields of crops planted in the field trials.

4.2 Application of the CROPWAT model

CROPWAT was developed by the FAO Land and Water Development Division (FAO, 1992). It includes a simple water balance model that allows the simulation of crop deficit irrigation conditions and estimation of yield reductions based on well established methodologies for determining crop evapotranspiration and yield responses to water (FAO, 1979). The CROPWAT model can adequately simulate yield reduction as a result of imposed deficit irrigation. It accounts well for the relative sensitivity of different growth stages and it is able to reproduce the negative impact of deficit irrigation on yield.

4.2.1. Methodology

CROPWAT (version 4.3) is a computer program based on the FAO (1992) Penman-Monteith combination method for calculating reference crop evapotranspiration (ETo) values. These estimates are used in crop water requirement and irrigation scheduling calculations.

The FAO Penman-Monteith method can be expressed as (Allen et al. 1998):

$$ET_o = \frac{0.408\,\Delta\,(R_n - G) + \gamma \frac{900}{T+273} u_2\,(es\text{-}ea)}{\Delta + \gamma\,(1 + 0.34 u_2)}$$

Where:
ET_o is the reference evapotranspiration (mm day^{-1})
R_n is the net radiation at the crop surface (MJ m^{-2} day^{-1})
G is the soil heat flux density (MJ m^{-2} day^{-1})
T is the mean daily air temperature at 2 m height (°C)
u_2 is the wind speed at 2 m height (m s^{-1})
es is the saturation vapor pressure (kPa)
ea is the actual vapor pressure (kPa)
es-ea is the vapor pressure deficit (kPa)
Δ is the slope of the vapor pressure-temperature curve (kPa $°C^{-1}$)
γ is a psychometric constant (kPa $°C^{-1}$)

Crop water requirements (ET_{crop}) over the growing season are determined from ET_o and estimates of crop evaporation rates, expressed as a crop coefficient, (K_c) according to the following equation:

$$\text{Crop water requirement } (ET_{crop}) = ET_o * K_c$$

The effect of water stress on yield is quantified by relating the relative yield decrease to the relative evapotranspiration deficit by an empirically derived yield response factor (K_y) expressed as:

$$K_y = \frac{(1 - \frac{Y_a}{Y_m})}{(1 - \frac{ET_a}{ET_m})}$$

Where:
Y_a is the actual yield
Y_m is the maximum yield
ET_a is the actual evapotranspiration
ET_m is the maximum evapotranspiration

The model was calibrated using weather, soil, and crop data for El-Bustan area. The effect of different irrigation scheduling scenarios and sowing dates on crop water requirements and crop productivity were tested for three crops – wheat, maize, and peanuts. Wheat was planted under sprinkler irrigation (5 day irrigation interval) where five sowing dates were tested, October 15, November 1, November 15, December 1, and December 15. The irrigation scheduling scenarios for wheat are presented in Table 4.1.

Maize was grown under drip irrigation (2 days irrigation interval). The tested sowing dates were: May 1, May 15, June 1, June 15, July 1, and July 15. Table 4.2 and Table 4.3 show the irrigation scheduling scenarios for maize and peanut, respectively.

The model was validated using measured field data for the wheat crop during the 2005-2006 winter season at two sites, El-Bustan, representing the new lands, and

Table 4.1. Irrigation scheduling scenarios for wheat.

Irrigation scheduling scenario	Growth stage			
	Net irrigation requirements (%)			
	Initial (I)	Develop. (II)	Mid. (III)	Late (IV)
1	100	100	100	100
2	75	75	75	75
3	50	50	50	50
4	50	75	100	100
5	50	100	100	50

Table 4.2. Irrigation scheduling scenarios for maize.

Irrigation scheduling scenario	Growth stage			
	Net irrigation requirements (%)			
	Initial (I)	Develop. (II)	Mid. (III)	Late (IV)
1	100	100	100	100
2	75	75	75	75
3	75	75	100	75
4	75	100	100	75
5	50	50	50	50
6	50	100	100	50
7	50	75	100	50
8	50	75	100	75

Table 4.3. Irrigation scheduling scenarios for peanut.

Irrigation scheduling scenario	Growth stage			
	Net irrigation requirements (%)			
	Initial (I)	Develop. (II)	Mid. (III)	Late (IV)
1	100	100	100	100
2	75	75	75	75
3	75	100	100	75
4	50	50	50	50
5	50	100	100	50

Monofia, representing the old lands. Four farms in the old lands and three farms in the new lands were selected for the on-farm trials on the wheat crop and the appropriate interventions suitable for each site were applied.

For the wheat planted in El-Monofia, four irrigation treatments were used. These were

1. Full irrigation (ET + 0.2 ET as a leaching requirement – I_{FULL}) under researcher supervision
2. Deficit irrigation (irrigation with 70% of full irrigation – $I_{0.7FULL}$) under researcher supervision
3. Wide furrow irrigation (done by combining two furrows and five wheat rows sown on each wide furrow) which was compared to the traditional separate furrows (two rows sown on each furrow), ($I_{W\text{-}FURROW}$), irrigated by the farmers with the amount of water applied being measured by the researcher, and
4. The farmers' irrigation treatment, (I_{FARMER}). Irrigation by the farmer with the amount of water applied being measured by the researcher.

At El-Bustan, three irrigation treatments were proposed

1. Full irrigation (ET + 0.2 ET as leaching requirement, I_{FULL}) under researcher supervision
2. Deficit irrigation (irrigation with 80% of

full irrigation, $I_{0.8FULL}$) under researcher supervision, and

3. Farmers' irrigation treatment, (I_{FARMER}); irrigation by the farmer with the amount of water applied being measured by the researcher.

Weather data, crop data, and soil data are included in Annex 1.

4.2.2. Results and Discussion

Calibration of the model has been done both for sowing date and irrigation scheduling.

The effect of the sowing date on the water requirements of wheat, peanut, and maize crops at El-Bustan area is presented in Table 4.4. For the wheat crop, the results indicate that crop water requirements (ET_{crop}) increased from 245.3 mm to 356.0 mm as the sowing date progressed from October 15 to December 15. Also, the net irrigation requirements increased from 241.2 mm to 349.0 mm for the respective sowing dates.

Comparing the changes in water requirements and expected yields with the same values for the optimum sowing date, Nov. 15, showed that the water requirements were -13.08% for the October 15 sowing date, -8.04% for the November 1 sowing, +12.69% for the December 1 sowing, and +26.15% for the December 15 sowing. The corresponding changes in yields were -20%, -5%, 0%, and -15% for these sowing dates.

From the results obtained, it could be concluded that wheat could be sown in El-Bustan area during the first half of November with a saving of about 8% in

Table 4.4. Effect of sowing dates on wheat, peanut, and maize crop water requirements.

Crop	Sowing date	ET_{crop} (mm)	Net irrigation (mm)	Yield expected (%)	ET change (%)	Yield change (%)
Wheat	Oct 15	245.30	241.20	80.00	-13.08	-20.00
	Nov 1	259.50	254.70	95.00	-8.04	-5.00
	Nov 15	282.20	276.80	100.00	0.00	0.00
	Dec 1	318.00	312.00	100.00	12.69	0.00
	Dec 15	356.00	349.00	85.00	26.15	-15.00
Peanut	Apr 1	520.80	507.20	95.00	-4.00	-5.00
	Apr 15	535.60	522.40	100.00	-1.27	0.00
	May 1	542.50	530.10	100.00	0.00	0.00
	May 15	539.60	528.20	90.00	-0.53	-10.00
	Jun 1	524.90	514.80	80.00	-3.24	-20.00
Maize	May 1	523.60	521.10	100.00	2.93	0.00
	May 15	508.70	506.40	100.00	0.00	0.00
	Jun 1	499.20	497.30	90.00	-1.87	-10.00
	Jun 15	465.00	463.20	80.00	-8.59	-20.00
	Jun 25	466.20	464.70	75.00	-8.35	-25.00
	Jul 1	429.36	427.80	70.00	-15.60	-30.00
	Jul 15	393.32	392.00	60.00	-22.68	-40.00

the irrigation water required; the resulting reduction in yield would be about 5%.

For the peanut crop, the results indicate that the highest ETc value of 542.5 mm was obtained for the optimum sowing date, May 1. They show also that, delaying the sowing dates to May 15 and June 1 resulted in 10% and 20% yield reductions. From the results obtained, it could be concluded that the best sowing time for a peanut crop in El-Bustan area is the period from April 15 to May 1. Peanut crops sown in this period were not subject to any yield reductions.

The data also show that the earliest (April 1) as well as the latest (June 1) sowings are not to be recommended. No appreciable water savings were achieved for sowings on either of these dates. Indeed, sowings on both dates negatively affected the yield. By delaying sowing until June 1, the yield was 20% lower than that recorded for the optimum sowing date.

For the maize crop, sowings on the optimal dates (May 1 and May 15) were accompanied by the highest crop water requirement values of 523.6 mm (May 1) and 508.7 mm (May 15). The results also show that the yield reduction for maize was increased from 10% to 40% with delays in the sowing date between June1 and July 15. Also, the ETcrop values were from 2% to 23% less than those for the optimum sowing dates. From the results obtained it could be concluded that the sowing date had a greater effect on the yield obtained than on the water requirements.

Data presented in Table 4.4 also show that the gradual delay in the sowing time resulted in a gradual reduction in the yield produced as well as in the ETcrop values. However, its negative effect was much more evident on the yield than on the maize water requirements.

In the El-Bustan area, where water is a limiting factor for agricultural production, the question to be answered is, "Is saving 20% in the amount of water applied, with the associated 40% reduction in yield resulting from delaying sowing until July 15, a sustainable way to meet the water shortage?" To answer the question, the crop water productivity needed to be measured.

The effects of different irrigation scheduling scenarios on the irrigation requirements and yields of wheat, peanut, and maize crops in El-Bustan area are presented in Tables 4.5, 4.6, and 4.7. For the wheat crop, (Table 4.5), the results show that irrigating with amounts of water equal to 75% and 50% of the actual crop water requirements for the whole season resulted in 12.6% and 35.6% yield reductions and 26.22% and 50.7% savings in irrigation water. The results also revealed that irrigating wheat with amounts of water equal to 50%, 75%, and 100% of the required water during the initial, development, mid-, and late-season growth stages, respectively, resulted in a 4.0% yield decrease and a 17.25% saving in irrigation water. Also, irrigating with 50% of the required water during the initial and

Table 4.5. Effect of irrigation scenarios on wheat yield and water requirements.

Wheat crop irrigation scenario	ET_c (mm)	Net irrigation (mm)	Predicted yield reduction (%)	Water saved (mm)	Water saved (%)
1) 100% at all stages	282.18	276.80	0.000	5.38	1.91
2) 75% at all stages	246.80	208.20	12.600	73.98	26.22
3) 50% at all stages	181.80	139.10	35.600	143.08	50.71
4) 50/75/100/100	270.90	233.50	4.000	48.68	17.25
5) 50% at stages I and IV	270.50	228.00	4.100	54.18	19.20

Table 4.6. **Effect of irrigation scenarios on peanut yield and water requirements.**

Peanut crop irrigation scenario	ET_c (mm)	Net irrigation (mm)	Predicted yield reduction (%)	Water saved (mm)	Water saved (%)
1) 100% at all stages	543	530	1.000	20.49	0.00
2) 75% at all stages	430	398	15.300	152.79	27.75
3) 75% at stages I and IV	523	491	3.500	59.59	10.82
4) 50% at all stages	302	264	31.600	286.29	52.00
5) 50% at stages I and IV	490	452	7.700	98.59	17.91

Table 4.7. **Effect of irrigation scenarios on maize yield and water requirements.**

Maize crop irrigation scenario	ET_c (mm)	Net irrigation (mm)	Predicted yield reduction (%)	Water saved (mm)	Water saved (%)
1) 100% all stages	508.70	506.40	0.00	2.30	0.45
2) 50% all stages	294.00	248.50	52.70	260.20	51.15
3) 50% stages I and IV	490.10	444.70	4.60	64.00	12.58
4) 75% all stages	417.20	372.80	22.50	135.90	26.72
5) 75% stages I and IV	508.70	470.40	0.00	38.30	7.53
6) 75% stages I, II, and IV	469.80	426.10	9.50	82.60	16.24
7) 50/75/100/50	446.00	400.50	15.40	108.20	21.27
8) 50/75/100/75	459.50	415.70	12.10	93.00	18.28

late-season growth stages resulted in a 4.1% yield reduction and a 19.2% saving in irrigation water.

Comparing the different irrigation scenarios concerning, on the one hand, the changes in yield and, on the other hand, the water saving percentages, it is quite evident that, in the case of a water shortage irrigation scheduling scenarios 4 and 5 should be followed, minimizing the yield reduction and saving more than 17% of the irrigation water.

For the peanut crop, (Table 4.6), irrigation with amounts of water equal to 75% and 50% of the crop water requirements resulted in 15.3% and 31.6% yield reductions and 27.75% and 52% savings in irrigation water. Irrigating the peanut crop with amounts of water equal to 75% of the requirement during the initial and late-season growth stages resulted in a 3.5% yield reduction and about an 11% saving in irrigation water. Irrigating with amounts of water equal to 50% of the required amount during the same growth stages resulted in a 7.7% yield reduction and about an 18% saving in water. Therefore, under conditions of limited available water resources and for areas suffering a water shortage, irrigating with amounts of water equal to 30% of that required during the initial and late season growth stages is the strategy to be recommended. The second best strategy to adopt for these conditions would be irrigating during the same growth stages with 75% of the peanut crop water requirements. Following both these irrigation scenarios, it is possible to minimize yield losses while at the same time maximizing water savings.

For the maize crop, (Table 4.7), irrigating with amounts of water equal to 75% and 50% of the crop water requirements for the whole season resulted in 22.5% and 52.7% reductions in maize yield and in 26.72% and 51.15% savings in irrigation water. Irrigating with amounts of water equal to 75% of the crop water requirements during the initial and late-season growth stages resulted in saving about 7.5% of the irrigation water without any reduction in yield. Irrigating with the same amounts of water during the initial, developing and late-season growth stages resulted in a 9.5% reduction in the yield and in saving about 16.24% in irrigation water. Also, irrigating with amounts of water equal to 50% of the crop water requirements during growth stages I and IV resulted in a 4.6% reduction in maize yield and a 12.6% saving in irrigation water. Under water shortage conditions, among the eight irrigation scenarios tested, the recommended ones are numbers three, five, and six for their superiority in minimizing yield reductions and improving water saving.

Old lands site (El-Monofia)

The measured field data and the predicted data for Monofia site are presented in Table 4.8. The results indicate that the actual amounts of irrigation water applied by the farmers for wheat were close to those calculated by the model. The results also indicate that there was close agreement between the actual (Yact) and predicted (Y_p) yields. The ratio (Y_p/Y_{act}) was not less than 0.984.

New lands site (El-Bustan)

The measured field data and the predicted data for El-Monofia site are presented in Table 4.8. The results indicate that the actual amounts of irrigation water applied by the farmers were less than those calculated by the model.

The results also show that there was close agreement between the actual (Y_{act}) and predicted (Y_p) yields. Table 4.9 summarizes the data for El-Bustan site. The trend of the experimental data is more or less similar to that at El-Monofia site. The ratio (Y_p/Y_{act}) varied between 0.87 (Sharab farmer and

Table 4.8. Measured and predicted data at the Monofia site, planting date Nov. 17 and seasonal effective rainfall 51 mm.

Name	ET_o (mm)	ET_m (mm)	Irr_{req} (mm)	EIW (mm)	Farmer irrigation treatment				Full irrigation treatment			
					ET_c (mm)	EIW_{act} (mm)	Y_{act} (t/ha)	Y_p (t/ha)	ET_c (mm)	EIW_{act} (mm)	Y_{act} (t/ha)	Y_p (t/ha)
Salam	392.9	313.5	262.4	524.8	308.5	534.0	9.440	9.289	308.5	526.7	8.000	7.872
Badr	395.2	315.9	264.9	529.7	313.5	557.1	7.607	7.554	313.5	550.5	8.321	8.263
Khatab	392.9	313.5	264.9	529.7	311.1	538.8	9.429	9.353	311.1	555.9	9.321	9.246
Maher	392.9	313.5	262.4	524.8	308.5	510.9	7.750	7.626	308.5	503.1	7.679	7.556
Salam	392.9	313.5	262.4	524.8	308.5	419.5	10.440	10.273	308.5	383.6	10.000	9.840
Badr	395.2	315.9	264.9	529.7	313.5	429.8	7.393	7.341	313.5	448.1	8.607	8.547
Khatab	392.9	313.5	264.9	529.7	311.1	435.5	9.464	9.388	311.1	400.2	8.964	8.892
Maher	392.9	313.5	262.4	524.8	308.5	396.0	6.646	6.540	308.5	350.2	8.393	8.259

Note: ET_o – reference crop evapotranspiration (FAO, P-M); $Rain_{eff}$ – effective rainfall; ET_m – non-stressed crop ET; ET_c – actual crop ET in the field; Irr_{req} – irrigation requirements (ET_m – $Rain_{eff}$); Y_{act} – actual yield EIW – estimated irrigation water requirement = [(Irr_{req}/ET_a) * LR]; LR – leaching requirements = 1.2; AIW_{act} – actual amount of applied irrigation water, Y_p – predicted yield.

Table 4.9. Measured and predicted data at El-Bustan site.

Name	Sowing date	ET_o (mm)	$Rain_{eff}$ (mm)	ET_m (mm)	Irr_{req} (mm)	AIW (mm)	Farmers' irrigation treatment				Full irrigation treatment				80% irrigation treatment			
							ET_c (mm)	AIW_{act} (mm)	Y_{act} (t/ha)	Y_p (t/ha)	ET_c (mm)	AIW_{act} (mm)	Y_{act} (t/ha)	Y_p (t/ha)	ET_c (mm)	AIW_{act} (mm)	Y_{act} (t/ha)	Y_p (t/ha)
Hala	Nov 21	421.3	15.0	336.7	321.7	454.2	331.7	412.0	5.786	5.699	315.2	411.4	6.750	6.318	307.1	335.9	6.110	5.572
Khalid	Nov 29	440.2	14.1	356.5	341.4	482.0	352.7	410.5	3.893	3.854	350.5	352.8	4.214	4.142	338.4	303.6	3.857	3.660
Sharab	Nov 23	425.7	15.1	341.4	326.3	453.6	325.8	408.6	3.929	3.748	315.1	367.8	3.750	3.461	297.5	300.0	3.714	3.235

80% irrigation treatment) and 0.99 (Khalid farmer and farmers' irrigation treatment).

Putting together the data summarized in Tables 4.8 and 4.9, it can be seen that the CROPWAT model can be used for irrigation scheduling and predicting the effect on crop yield and reductions in the amounts of irrigation water under both El-Bustan (new lands) and Monofia (old lands) conditions.

4.3 Yield-Stress model

The Yield-Stress model (Ouda, 2006) was developed, based on the same approach that CROPWAT uses. It estimates the amount of soil water reserved in the root zone area and determines crop evapotranspiration using a different method for the calculation of yield reduction as a result of deficit irrigation. Basically, the Yield-Stress model assumes that there is a linear relationship between available water and yield. Reduction in available water limits evapotranspiration and consequently reduces the yield. This assumption is supported by the previous work of several researchers (de Wit, 1958; Childs and Hanks, 1975; Bresler, 1987; Shani and Dudley, 2001).

The Yield-Stress model was designed to predict the effect of deficit irrigation scheduling on the yield of several crops and their consumptive water use (CWU). The model was used for the irrigation management of different crops under different stress conditions and its performance was acceptable.

4.3.1. Methodology

The main purpose of Yield-Stress model (Ouda 2006) is to predict crop yield under deficit irrigation for certain farms, based on the measured yield under no water stress. The Yield-Stress model uses a daily time step and requires two types of input data – input data by the user and an input data file. The model asks the user to input the planting and harvesting dates, the length of the growing season, crop yield, and soil characteristics – percent of clay, silt, sand, organic matter, and CaCO3.

The other input data source is a file representing the whole growing season, starting with the sowing month and date, and ending with the harvesting month and date. The file contains maximum, minimum, and mean temperatures, relative humidity, solar radiation, wind speed, the FAO's crop coefficient, and the date of and amount of water supplied at each irrigation. The model has three main components – the soil water balance calculation, salinity stress, and crop yield calculation routines.

The soil water balance is determined by calculating the readily available water at the root zone using equations described in FAO publication No 56 (FAO, 1998) as follows.

$TAW = (W_{FC}-W_{WP})\ Z$

$RAW = p\ TAW$

Where:
TAW is the total available water (mm)
W_{FC} is the water at field capacity (mm)
W_{WP} is the water at the wilting point (mm)
Z is the rooting depth (mm)
RAW is the readily available water (mm)
P is the soil water depletion fraction under no stress

The reference evapotranspiration (mm/day) was calculated using the Penman-Monteith equation (Allen et al., 1998) as follows:

$$ET_o = \frac{0.408\,\Delta\,(R_n - G) + \gamma \frac{900}{T+273} u_2\,(es\text{-}ea)}{\Delta + \gamma\,(1 + 0.34 u_2)}$$

Where:
ET_o is the reference evapotranspiration (mm day^{-1})
R_n is the net radiation at the crop surface (MJ m^{-2} day^{-1})
G is the soil heat flux density (MJ m^{-2} day^{-1})
T is the mean daily air temperature at 2 m height (°C)
u_2 is the wind speed at 2 m height (m s^{-1})
es is the saturation vapor pressure (kPa)
ea is the actual vapor pressure (kPa)

es-ea is the vapor pressure deficit (kPa)
Δ is the slope of the vapor pressure-temperature curve (kPa $^{o}C^{-1}$)
γ is a psychometric constant (kPa $^{o}C^{-1}$)

Crop evapotranspiration (ET_{crop}) is calculated by multiplying ET_o by the crop coefficient (K_c):

$$ET_{crop} = K_c\ ET_o$$

The model calculates the root zone depletion (D_r) by accumulating the ET_{crop} and comparing it on a daily basis with the readily available water. If the root zone depletion is higher than the readily available water, a deficit irrigation coefficient (K_s) is calculated and used to calculate an adjusted ET_{crop}, (ET_{cadj} mm day^{-1}) (FAO,. 1998).

$$K_s = (TAW-D_r)/((1-p)*TAW)$$

$$ET_{cadj} = K_s\ ET_{crop}$$

The salinity stress effect is calculated if the value of the irrigation water EC (EC_e) is higher than the EC threshold (EC_{es}). Under that condition, another water stress coefficient is calculated to combine the effect of water stress and salinity stress and a new value for ET_{cadj} is calculated (FAO, 1998).

$$K_{ss} = \left(1 - \frac{b}{K_y 100}(EC_e - EC_{es})\left(\frac{TAW - D_r}{(1-p)TAW}\right)\right)$$

Where:
b is the percent reduction in crop yield per unit dS m^{-1} increase in EC_e beyond the EC_e threshold
K_y is the yield response factor
EC_e is the electrical conductivity of a soil water solution after the addition of a sufficient quantity of distilled water to bring the soil water content to saturation.
EC_{es} is the EC of the saturation extract at the threshold of EC_e when the crop yield is reduced.

The old version of the model calculated crop yield on a daily basis as a function of water consumption. The model calculated a value for the accumulated yield per day throughout the growing season (Y_{mean}) by dividing the measured yield at the farm level ($Y_{measured}$) by the measured season length (SL):

$$Y_{mean} = Y_{measured}/SL$$

However, the model was modified to calculate dry matter production using the solar energy level as the limiting factor (Loomis and Williams, 1963). This method converts total solar radiation to micro-Einstein (μE). Then, it assumes that 82% of the visible light is intercepted by chloroplasts with a maximum quantum efficiency of 10% (10 photons reduce one CO_2 molecule). Furthermore, the method subtracts 33% of the gross photosynthesis as a respiration cost to calculate the net photosynthesis, which is converted from μmoles cm^{-2} to g m^{-2} dry matter produced per day.

The model accounts for water stress when the predicted readily available water is greater than the predicted ET_{crop}. If the predicted readily available water is lower than the predicted ET_{crop}, K_s will be less than 1 and the value of the predicted yield ($Y_{predicted}$) will be reduced in relation to the reduction in daily water consumption as follows:

$$Y_{predicted} = K_s\ Y_{predicted}$$

The Yield-Stress model was calibrated using crop data from the Resource Management Program of ARC, Egypt, in collaboration with ICARDA (long-term trials). The model was used to predict the yield and CWU of the six crops as indicated below under actual irrigation amounts and under four proposed deficit irrigation treatments:

- Cotton – data from six growing seasons were available for two sites, Beni Sweif and Damietta.
- Clover, soybeans, and wheat – data from four growing seasons were available for the Beni Sweif site.
- Onions and faba beans – data from three growing seasons were available for the Beni Sweif site.

These six crops were irrigated with either fresh water or agricultural drainage water. The salinity level of the agricultural drainage water was low, which did not pose any salinity stress on the growing crops. The model is calibrated by adjusting the crop K_c, which allows the model to predict both yield and CWU accurately. The model's predictions were compared to the measured data and the percent reduction between the measured and predicted values for each growing season was calculated; in addition to two goodness of fit measurements – the root mean squared error (Jamieson et al., 1998) and the Willmott index of agreement (Willmott, 1981).

After calibrating the model, it was used to predict the yield and CWU for the six crops under study under deficit water applications. For cotton, several deficit irrigation scenarios were used, 80%, 70%, 60%, and 50% of the total amount of required irrigation water. For clover, faba bean, onions, and soybeans, amounts of irrigation water equal to 95%, 90%, 85%, and 80% of the crop CWU were applied. The model was used to predict the wheat yield and CWU under 90%, 85%, 80%, and 75% of total amount of the crop irrigation water requirements.

The model was validated using field data for wheat gathered during the 2005-2006 winter season at two sites, El-Monofia, representing the old lands, and Damietta, representing marginal lands (salt affected soil). Four farms on the old lands and six farms on the marginal lands were chosen. On the marginal lands, two farms used fresh water for irrigation, and two farms used either fresh or agricultural drainage water, depending on the availability of the fresh water in the misqa. The rest of the farms used agricultural drainage water for irrigation. Two irrigation treatments were used at the two sites to validate the model. On the old lands, two tests were conducted. The first allowed the farmers to use traditional irrigation practices and quantities of water while the second test used about 80% of the farmers' traditional volumes of water. On marginal lands, instead of 80%, about 75% of farmers' usual volumes of irrigation water were used. After validating the model, it was used to predict wheat yield and CWU for a 30% reduction of the total irrigation amounts at the two sites.

Two farms were chosen at El-Serw site where agricultural drainage water was used for irrigating wheat in the 2005-2006 growing season. These two farms were located at Kharg El-Zemam, where the soil is characterized by being saline-alkaline. Soil EC was 9.5 dS/m for Farm 1 and 6.8 dS/m for Farm 2. Wheat can tolerate salinity up to 6 dS/m, so salinity stress existed at both farms. The Yield-Stress model can simulate the effect of salinity stress on wheat yield, where a salinity stress coefficient (Kss) is calculated by the model and used to reduce the CWU and yield. Two irrigation treatments were used one involving the farmers' traditional irrigation volumes and the other using about 80% of these.

4.3.2 Results and discussion

The results, presented in Tables 4.10, 4.11, 4.12, 4.13, 4.14, and 4.15, showed clearly the accuracy of the model in predicting the yield of the six crops studied. That accuracy can be attributed to the method that the Yield-Stress model used in predicting yield under no water stress conditions. Similar results were obtained for soybean (Ouda et al., 2007 and Ouda et al., 2008c), wheat (Ouda 2006; El-Mesiry et al., 2007 and Ouda et al., 2008a) and sesame (Tantawy et al., 2007).

However, the model was less accurate in predicting CWU for some of the growing seasons (Tables 4.16, 4.17, 4.18, 4.19, 4.20, and 4.21), especially for cotton and onions. Similar results were obtained for maize (Ouda et al., 2007 and Ouda et al., 2008b) and barley (Khalil et al., 2007).

Table 4.10. Actual and predicted yield for cotton planted at Beni Sweif and El-Serw sites.

Location	Year	Fresh water irrigation			Drainage water irrigation		
		Yield (t/ha)		Reduction (%)	Yield (t/ha)		Reduction (%)
		Actual	Predicted		Actual	Predicted	
Beni Sweif	1997	3.80	3.80	0	4.33	4.33	0
	1998	2.10	2.10	0	2.20	2.20	0
	2000	3.25	3.25	0	3.16	3.11	1.58
	2001	2.72	2.71	0.37	2.81	2.79	0.71
El-Serw	1999	3.12	3.12	0	3.36	3.35	0.30
	2002	1.71	1.71	0	2.07	2.07	0
RMSE	0.0002				0.0102		
Willmott index	0.9999				0.9999		

Note: RMSE – root mean square error

Table 4.11. Actual and predicted yield of clover planted at Beni Sweif under fresh and drainage water irrigation.

Season	Fresh water irrigation			Drainage water irrigation		
	Yield (t/ha)		Reduction (%)	Yield (t/ha)		Reduction (%)
	Actual	Predicted		Actual	Predicted	
1997-1998	5.29	5.21	1.51	4.97	4.83	2.82
1998-1999	7.88	7.88	0.00	8.74	8.74	0.00
1999-1000	7.66	7.59	0.91	7.51	7.48	0.40
2000-2001	7.55	7.43	1.59	7.88	7.75	1.65
RMSE	0.0188			0.0221		
Willmott index	0.9999			0.9999		

Note: RMSE – root mean square error

Table 4.12. Actual and predicted yield of soybeans planted at Beni Sweif under fresh and drainage water irrigation.

Season	Fresh water irrigation			Drainage water irrigation		
	Yield (t/ha)		Reduction (%)	Yield (t/ha)		Reduction (%)
	Actual	Predicted		Actual	Predicted	
1998	1.21	1.20	0.83	1.34	1.33	0.75
1999	2.26	2.24	0.88	1.78	1.77	0.56
2000	1.73	1.70	1.73	1.56	1.54	1.28
2001	1.73	1.67	3.47	0.88	0.86	2.27
RMSE	0.0340			0.0189		
Willmott index	0.9998			0.9999		

Note: RMSE – root mean square error

Table 4.13. Actual and predicted yield of wheat planted at Beni Sweif under fresh water and drainage water irrigation.

Season	Fresh water irrigation			Drainage water irrigation		
	Yield (t/ha)		Reduction (%)	Yield (t/ha)		Reduction (%)
	Actual	Predicted		Actual	Predicted	
1998-1999	5.28	5.28	0	5.23	5.23	0
1999-2000	5.73	5.73	0	4.73	4.73	0
2000-2001	5.74	5.73	0.17	6.32	6.31	0.16
2001-2002	6.82	6.79	0.44	6.55	6.52	0.46
RMSE	0.0044			0.0046		
Willmott index	0.9999			0.9999		

Note: RMSE – root mean square error

Table 4.14. Actual and predicted yield of faba bean planted at Beni Sweif under fresh and drainage water irrigation.

Season	Fresh water irrigation			Drainage water irrigation		
	Yield (t/ha)		Reduction (%)	Yield (t/ha)		Reduction (%)
	Actual	Predicted		Actual	Predicted	
1998-1999	2.90	2.88	0.69	2.37	2.37	0
1999-2000	3.62	3.60	0.55	4.08	4.08	0
2001-2002	2.22	2.20	0.90	2.01	2.00	0.50
RMSE	0.0132			0.0039		
Willmott index	0.9999			0.9999		

Note: RMSE – root mean square error

Table 4.15. Actual and predicted yield of onions planted at Beni Sweif under fresh and drainage water irrigation.

Season	Fresh water irrigation			Drainage water irrigation		
	Yield (t/ha)		Reduction (%)	Yield (t/ha)		Reduction (%)
	Actual	Predicted		Actual	Predicted	
1998-1999	18.37	18.33	0.22	15.33	15.3	0.20
1999-2000	11.43	11.42	0.09	10.07	10.06	0.10
2001-2002	12.09	12.09	0	9.48	9.48	0
RMSE	0.0032			0.0030		
Willmott index	0.9999			0.9999		

Note: RMSE – root mean square error

Table 4.16. Actual and predicted CWU for cotton planted at two sites.

Location	Year	Fresh water irrigation			Drainage water irrigation		
		Water used (cm)		Reduction (%)	Water used (cm)		Reduction (%)
		Act.	Pred.		Act.	Pred.	
Beni Sweif	1997	52.02	54.61	4.98	59.41	54.61	8.08
	1998	69.57	67.42	3.09	71.10	67.40	5.20
	2000	68.62	68.46	0.23	73.93	68.84	6.88
	2001	72.93	74.49	2.14	74.38	74.61	0.31
El-Serw	1999	57.50	56.32	2.05	53.90	56.94	5.64
	2002	58.80	58.89	0.15	56.70	58.89	3.86
RMSE		0.0343			0.0780		
Willmott index		0.9998			0.9992		

Note: RMSE – root mean square error

Table 4.17. Actual and predicted CWU for clover planted at Beni Sweif under fresh and drainage water irrigation.

Season	Fresh water irrigation			Drainage water irrigation		
	Water used (cm)		Reduction (%)	Water used (cm)		Reduction (%)
	Actual	Predicted		Actual	Predicted	
1997-1998	22.30	22.82	2.33	22.94	22.68	1.13
1998-1999	20.53	20.46	0.34	20.78	20.46	1.54
1999-2000	26.01	26.35	1.31	26.17	26.36	0.73
2000-2001	26.35	27.72	5.20	26.36	27.72	5.16
RMSE	0.0527			0.0496		
Willmott index	0.9996			0.9997		

Note: RMSE – root mean square error.

Table 4.17. Actual and predicted CWU for clover planted at Beni Sweif under fresh and drainage water irrigation.

Season	Fresh water irrigation			Drainage water irrigation		
	Water used (cm)		Reduction (%)	Water used (cm)		Reduction (%)
	Actual	Predicted		Actual	Predicted	
1997-1998	22.30	22.82	2.33	22.94	22.68	1.13
1998-1999	20.53	20.46	0.34	20.78	20.46	1.54
1999-2000	26.01	26.35	1.31	26.17	26.36	0.73
2000-2001	26.35	27.72	5.20	26.36	27.72	5.16
RMSE	0.0527			0.0496		
Willmott index	0.9996			0.9997		

Note: RMSE – root mean square error.

Table 4.18. Actual and predicted CWU for soybeans planted at Beni Sweif under fresh and drainage water irrigation.

Season	Fresh water irrigation			Drainage water irrigation		
	CWU (cm)		Reduction (%)	CWU (cm)		Reduction (%)
	Actual	Predicted		Actual	Predicted	
1998	34.67	33.40	3.66	35.68	34.72	2.69
1999	39.36	38.19	2.97	39.10	38.29	2.07
2000	37.26	36.75	1.37	37.90	36.83	2.82
2001	38.29	39.11	2.14	40.17	39.55	1.54
RMSE	0.0440			0.0384		
Willmott index	0.9998			0.9998		

Note: RMSE – root mean square error.

Table 4.19. Actual and predicted CWU for wheat planted at Beni Sweif under fresh and drainage water irrigation.

Season	Fresh water irrigation			Drainage water irrigation		
	CWU (cm)		Reduction (%)	CWU (cm)		Reduction (%)
	Actual	Predicted		Actual	Predicted	
1998-99	40.04	41.03	2.47	40.72	41.03	0.76
1999-00	41.28	41.88	1.45	42.64	41.88	1.78
2000-01	44.73	44.32	0.92	45.63	44.32	2.87
2001-02	44.90	45.84	2.09	46.66	45.84	1.76
RMSE	0.0301			0.0332		
Willmott index	0.9999			0.9998		

Note: RMSE – root mean square error.

Table 4.20. Actual and predicted CWU for faba bean planted at Beni Sweif under fresh and drainage water irrigation.

Season	Fresh water irrigation			Drainage water irrigation		
	CWU (cm)		Reduction (%)	CWU (cm)		Reduction (%)
	Actual	Predicted		Actual	Predicted	
1998-1999	30.93	30.71	0.71	31.69	31.63	0.19
1999-2000	33.94	33.36	1.71	35.46	33.57	5.33
2001-2002	35.45	34.62	2.34	35.61	34.67	2.64
RMSE	0.0344			0.0685		
Willmott index	0.9999			0.9996		

Note: RMSE – root mean square error.

Table 4.21. Actual and predicted CWU for onions planted at Beni Sweif under fresh and drainage water irrigation.

Season	Fresh water irrigation			Drainage water irrigation		
	CWU (m^3)		Reduction (%)	CWU (m^3)		Reduction (%)
	Actual	Predicted		Actual	Predicted	
1998-1999	20.66	20.41	1.21	21.16	20.49	3.17
1999-2000	20.92	20.34	2.77	21.32	20.44	4.13
2001-2002	21.46	21.03	2.00	22.06	21.13	4.22
RMSE	0.4040			0.0746		
Willmott index	0.9998			0.9994		

Note: RMSE – root mean square error.

4.3.3 Tested scenarios of deficit irrigation

Cotton yield

Predicted cotton yield under deficit irrigation - Beni Sweif site

The data representing the predicted yield (t/ha) and the percent reductions in yield under the different irrigation treatments using both fresh and drainage water are given in Table 4.22. The data presented show clearly that under deficit irrigation, gradual reduction in the volumes of water applied (up to 50%) did not result in any significant differences in the predicted yield (the reduction was less than 2%).

This was also the case in the 1998 growing season (Table 4.22). The data show that up to 30% of the total irrigation water could be saved with concomitant yield losses of less than 2% under both fresh and drainage water irrigation.

In the 2000 growing season (Table 4.22), the data show that irrigating with a volume of water not less than 70% of the full irrigation requirement did not result in any significant reduction in the predicted yield – it being 2% lower than that under full irrigation. However, reducing the volume of water applied water to 60% and 50% of the full irrigation requirement resulted in a drastic drop in yield – losses of 11% and 26% being observed.

From the data for the 2000 growing season it can be seen that there is a high potential for water saving (corresponding to nearly 30% of the full irrigation amount) with associated yield losses not exceeding 2%.

Likewise for the 2001 growing season (Table 4.22), for both irrigation water sources, nearly 40% of the water applied under the full irrigation treatment could be saved with an associated reduction in the cotton yield of around 3%.

Predicted cotton yield under deficit irrigation – El-Serw site

For cotton planted at El-Serw in the 1999 growing season (Table 4.23), the yield responded to deficit irrigation treatments in a manner completely different from that obtained at the Beni Sweif site.

The data reveal that under deficit irrigation, the lower the volume of water applied, the higher is the reduction in the predicted yield. Under irrigation with a volume of water amounting to 50% of the full requirement, the yield was seriously affected, with losses reaching 60% of that obtained under the full irrigation with fresh and/or drainage water. Reducing the amount of water applied to 80% of the full irrigation requirement also affected the predicted yield, but at a relatively lower amount – just 7% of that under full irrigation. This means that reducing the volume of water applied by more than

Table 4.22. Predicted cotton yield and its percent reduction under different deficit irrigation treatments using fresh and drainage irrigation water in four successive growing seasons 1998-2001 at Beni Sweif site.

Growing season 1997

Irrigation treatment	Fresh water irrigation		Drainage water irrigation	
	Predicted yield (t/ha)	Reduction (%)	Predicted yield (t/ha)	Reduction (%)
Total irrigation	3.80	0	4.33	0
80% of total irrigation	3.80	0	4.33	0
70% of total irrigation	3.80	0	4.33	0
60% of total irrigation	3.79	0.26	4.32	0.23
50% of total irrigation	3.73	1.84	4.29	0.92

Growing season 1998

Irrigation treatment	Fresh water irrigation		Drainage water irrigation	
	Predicted yield (t/ha)	Reduction (%)	Predicted yield (t/ha)	Reduction (%)
Total irrigation	2.10	0	2.20	0
80% of total irrigation	2.07	1.43	2.19	0.45
70% of total irrigation	2.06	1.90	2.17	1.36
60% of total irrigation	1.86	11.43	2.04	7.27
50% of total irrigation	1.55	26.19	1.75	20.45

Growing season 2000

Irrigation treatment	Fresh water irrigation		Drainage water irrigation	
	Predicted yield (t/ha)	Reduction (%)	Predicted yield (t/ha)	Reduction (%)
Total irrigation	3.25	0	3.11	0
80% of total irrigation	3.19	1.85	3.08	0.96
70% of total irrigation	3.01	7.38	2.92	6.11
60% of total irrigation	2.75	15.38	2.68	13.83
50% of total irrigation	2.41	25.85	2.34	24.76

Growing season 2001

Irrigation treatment	Fresh water irrigation		Drainage water irrigation	
	Predicted yield (t/ha)	Reduction (%)	Predicted yield (t/ha)	Reduction (%)
Total irrigation	2.71	0	2.79	0
80% of total irrigation	2.71	0	2.79	0
70% of total irrigation	2.71	0	2.79	0
60% of total irrigation	2.62	3.32	2.70	3.23
50% of total irrigation	2.40	11.44	2.49	10.75

Table 4.23. Predicted cotton yield and its percent reduction under different deficit irrigation treatments using fresh and drainage water in the 1998 and 2002 cropping seasons at El-Serw site.

Growing season 1998

Irrigation treatment	Fresh water irrigation		Drainage water irrigation	
	Predicted yield (t/ha)	Reduction (%)	Predicted yield (t/ha)	Reduction (%)
Total irrigation	3.12	0	3.35	0
80% of total irrigation	2.91	6.73	3.19	4.78
70% of total irrigation	2.50	19.87	2.74	18.21
60% of total irrigation	1.88	39.74	2.11	37.01
50% of total irrigation	1.29	58.65	1.46	56.42

Growing season 2002

Irrigation treatment	Fresh water irrigation		Drainage water irrigation	
	Predicted yield (t/ha)	Reduction (%)	Predicted yield (t/ha)	Reduction (%)
Total irrigation	1.71	0	2.07	0
80% of total irrigation	1.71	0	2.07	0
70% of total irrigation	1.66	2.92	2.07	0
60% of total irrigation	1.43	16.37	1.85	10.63
50% of total irrigation	1.06	38.01	1.40	32.37

20% of the full irrigation requirement is not recommended for crop production in El-Serw site.

We can see from the data that the amount of irrigation water applied in El-Serw in 1999, correctly matches the water requirements for cotton.

A comparison of the data for the 1998 and 2002 growing seasons shows that 30% of the water applied could be saved without any significant reduction in yield. The recorded loss was around 3% compared to the yield obtained under full irrigation which suggests that 'full irrigation' was actually over irrigation.

A comparison of the data for the 1998 and 2002 growing seasons shows that 30% of the water applied could be saved without any significant reduction in yield. The recorded loss was around 3% compared to the yield obtained under full irrigation which suggests that 'full irrigation' was actually over irrigation.

Predicted CWU for cotton under deficit irrigation – Beni Sweif site

Table 4.24 shows the predicted CWU, and its changes under deficit irrigation treatments, during four successive experimental seasons (1997 to 2001) for a cotton crop at the Beni Sweif site.

The data indicate that the reduction in CWU of the cotton crop followed a trend similar to that for the predicted yield reductions. As the volume of irrigation water was decreased so there was an accompanying decrease in the yield. This held true for both the fresh and drainage water irrigation scenarios. However, the magnitudes of the changes in yield associated with the different treatments varied greatly from one cropping season to the other. In addition, the data show that under the different deficit irrigation treatments, the percent reductions in the volumes of irrigation water used were always greater than the

Table 4.24. Percent reduction in predicted yield and CWU for cotton grown under different deficit irrigation treatments at the Beni Sweif site in the 1997 to 2001 growing seasons.

Growing season 1997

Irrigation treatment	Fresh water		Drainage water	
	Predicted yield reduction (%)	Predicted CWU reduction (%)	Predicted yield reduction (%)	Predicted CWU reduction (%)
Total irrigation	0	0	0	0
80% of total irrigation	0	0	0	0
70% of total irrigation	0	0	0	0
60% of total irrigation	0.26	0.18	0.23	0.11
50% of total irrigation	1.84	8.86	0.92	5.27

Growing season 1998

Irrigation treatment	Fresh water		Drainage water	
	Predicted yield reduction (%)	Predicted CWU reduction (%)	Predicted yield reduction (%)	Predicted CWU reduction (%)
Total irrigation	0	0	0	0
80% of total irrigation	1.43	1.71	0.45	0.21
70% of total irrigation	1.90	5.58	1.36	4.94
60% of total irrigation	11.43	19.58	7.27	15.24
50% of total irrigation	26.19	38.86	20.45	34.12

Growing season 2000

Irrigation treatment	Fresh water		Drainage water	
	Predicted yield reduction (%)	Predicted CWU reduction (%)	Predicted yield reduction (%)	Predicted CWU reduction (%)
Total irrigation	0	0	0	0
80% of total irrigation	1.85	5.49	0.96	5.75
70% of total irrigation	7.38	13.73	6.11	12.86
60% of total irrigation	15.38	24.45	13.83	22.31
50% of total irrigation	25.85	39.04	24.67	35.55

Growing season 2001

Irrigation treatment	Fresh water		Drainage water	
	Predicted yield reduction (%)	Predicted CWU reduction (%)	Predicted yield reduction (%)	Predicted CWU reduction (%)
Total irrigation	0	0	0	0
80% of total irrigation	0	1.44	0	1.43
70% of total irrigation	0	5.58	0	4.38
60% of total irrigation	3.32	15.14	3.23	13.89
50% of total irrigation	11.44	28.97	10.75	26.40

accompanying reductions in the yield. Moreover, by comparing the reductions in yield and CWU under the different deficit irrigation treatments, it can be seen that the percent reductions in yield under the drainage water treatments were lower than those found under irrigation with freshwater.

These variations in the yield values obtained, which are larger under freshwater irrigation than drainage water irrigation, could be attributed to the effect of drainage water on the vegetative growth. The drainage water reduced vegetative growth and development and, hence, reduced the CWU. This is very apparent when irrigation was practiced with volumes corresponding to 50% of the total irrigation.

Predicted cotton yield under deficit irrigation – El-Serw site

For El-Serw site (see Table 4.25), it is quite clear that, during the 1999 and 2002 growing seasons, the CWU as well as the yields of cotton obtained under the different deficit irrigation treatments followed a trend similar to the one previously discussed for the Ben Sweif site.

However, comparing the CWU for cotton at the two sites under investigation, it is quite clear that this parameter varies greatly with the variations in growing season and site.

For the 2002 season for the Beni Sweif site, the amounts of water used were relatively higher than those at El-Serw site in the same season. For the predicted percent CWU reduction, we found the opposite to be true. This parameter at El-Serw site was nearly two or three times greater than that at the Beni Sweif site. This was particularly evident under severe deficit irrigation treatments where irrigation was practiced with volumes of water amounting to 60% and 50% of the total irrigation volume.

For El-Serw site, the data also show that the predicted reductions in CWU and the yields associated with these reductions in

Table 4.25. Percent reduction in predicted yield and CWU of cotton grown under different deficit irrigation treatments at El-Serw site in the 1999 and 2002 growing seasons.

Growing season 1999

Irrigation treatment	Fresh water		Drainage water	
	Predicted yield reduction (%)	Predicted CWU reduction (%)	Predicted yield reduction (%)	Predicted CWU reduction (%)
Total irrigation	0	0	0	0
80% of total irrigation	6.73	8.17	4.78	6.90
70% of total irrigation	14.87	24.66	18.21	23.01
60% of total irrigation	39.74	48.05	37.01	45.08
50% of total irrigation	58.65	68.95	56.42	67.40

Growing season 2002

Irrigation treatment	Fresh water		Drainage water	
	Predicted yield reduction (%)	Predicted CWU reduction (%)	Predicted yield reduction (%)	Predicted CWU reduction (%)
Total irrigation	0	0	0	0
80% of total irrigation	0	0.80	0	0.12
70% of total irrigation	2.92	8.30	0	3.11
60% of total irrigation	16.37	22.16	16.63	15.44
50% of total irrigation	38.01	47.22	32.37	40.04

the in the volume of water applied, are greater for the 1999 growing season than for the 2002 season. This holds true for the investigated deficit irrigation treatments under both fresh water and drainage water irrigation. The variation in these two parameters in El-Serw site could be attributed to the differences in the climatic parameters between the 1999 and 2002 growing seasons.

Clover

Predicted clover yield under deficit irrigation

The data shown in Table 4.26 indicates that the gradual decrease in the volumes of irrigation water applied gradually reduced the clover yield. This was the case for four successive growing seasons. In the 1997-1998 growing season the clover yield under the fresh water irrigation treatments was an average of 4.95 t/ha, which corresponded to about 64% of the yields obtained in the following three successive seasons. The yields in these successive seasons were more or less similar under the different deficit irrigation treatments investigated.

Changing the irrigation water from fresh to drainage water did not result in any notable variations in the yield. During the growing season 1997-1998, under drainage water irrigation, the clover yield was slightly lower than that from freshwater; whereas in the 1998-1999 season it was slightly higher. Taking into consideration the two successive growing seasons 1999-2000 and 2000-2001, the variations in yield, resulting from irrigation with water of different qualities, was not significant – it remained essentially the same. Such data provide evidence that clover can be successfully irrigated with low salinity water, such as drainage water, without any notable deterioration in its yield.

The data indicate that irrigation under 90% of the full irrigation amount did not result in any notable losses in yield. Those that did occur varied from between 1.14% and 5.37% with an average value of 3.3%. This is a very satisfactory result since it represents a 10% saving in the amount of water to be applied water, while at the same time maintaining, a yield very close to that obtained when full irrigation is practiced. The data also show that for clover there are further potential savings of water while keeping the yield at values very similar to that when full irrigation is practiced. This was verified for the case where irrigation was practiced with 80% of the full irrigation volume. Irrigation under such volumes of water during four successive growing seasons resulted in an average yield reduction not exceeding 7% of that achievable under full irrigation.

For arid and semi-arid regions, such data are technically and economically sound. Furthermore, for areas suffering freshwater shortages, it is possible to irrigate clover with waters having a salinity level which the crop can tolerate, such as the drainage water in this case.

The beneficial effect will be the saving of relatively large quantities of freshwater, which can be used to expand the irrigated areas, compensating for water shortages in other sectors. The water saved can also be used to leach accumulated salts from the soil and to keep those soils under irrigation with saline water at a high productivity level.

Predicted water consumption for clover

Data concerning the percent reductions in predicted clover yield and the percent reductions in CWU during the four successive growing seasons – from 1997-1998 until 2000-2001 – under different deficit irrigation treatments are given in Table 4.27. The reductions in CWU for clover planted under fresh and drainage water deficit irrigation are shown in Figures 4.1 and 4.2.

The data show that under the deficit irrigation treatments, the percent reductions in the water used followed a trend similar to that characterizing the percent reductions for the clover yield. This clearly indicates the relationship that exists between the two parameters studied. The less the volume of irrigation water applied, the greater the percent decrease in both the clover yield

Table 4.26. Predicted clover yield and its percent reduction under different deficit irrigation treatments with fresh and drainage water.

Growing season 1997-1998

Irrigation treatment	Fresh water irrigation		Drainage water irrigation	
	Predicted yield (t/ha)	Reduction (%)	Predicted yield (t/ha)	Reduction (%)
Total irrigation	5.21	0	4.83	0
95% of total irrigation	5.04	3.26	4.74	1.86
90% of total irrigation	4.93	5.37	4.62	4.35
85% of total irrigation	4.84	7.10	4.45	7.87
80% of total irrigation	4.75	8.83	4.25	12.01

Growing season 1998-1999

Irrigation treatment	Fresh water irrigation		Drainage water irrigation	
	Predicted yield (t/ha)	Reduction (%)	Predicted yield (t/ha)	Reduction (%)
Total irrigation	7.88	0	8.74	0
95% of total irrigation	7.88	0	8.74	0
90% of total irrigation	7.79	1.14	8.74	0
85% of total irrigation	7.59	3.68	8.64	1.14
80% of total irrigation	7.34	6.85	8.42	3.66

Growing season 1999-2000

Irrigation treatment	Fresh water irrigation		Drainage water irrigation	
	Predicted yield (t/ha)	Reduction (%)	Predicted yield (t/ha)	Reduction (%)
Total irrigation	7.59		7.48	
95% of total irrigation	7.55	0.53	7.48	0.40
90% of total irrigation	7.42	2.24	7.39	1.60
85% of total irrigation	7.18	5.40	7.17	4.53
80% of total irrigation	6.91	8.96	6.96	7.32

Growing season 2000-2001

Irrigation treatment	Fresh water irrigation		Drainage water irrigation	
	Predicted yield (t/ha)	Reduction (%)	Predicted yield (t/ha)	Reduction (%)
Total irrigation	7.43	0	7.75	0
95% of total irrigation	7.16	3.63	7.45	3.87
90% of total irrigation	7.10	4.44	7.44	4.00
85% of total irrigation	6.98	6.06	7.36	5.03
80% of total irrigation	6.72	9.56	7.12	8.13

and CWU against their predicted values under full irrigation treatment. This was also the case when using drainage water for irrigation. However, under the drainage water irrigation scenario, during the four successive growing seasons, the percent reductions in water used were not equal to those predicted under irrigation with freshwater.

Generally, under irrigation with water of EC values exceeding that of fresh water, it is expected that the predicted percent reductions in the CWU under the deficit irrigation treatments would be lower than those obtained when irrigating with freshwater. This was quite evident for cotton.

For clover irrigated with drainage water, the percent reductions in the water used under the deficit irrigation treatments were either very near to or slightly greater than those predicted when irrigation was practiced with freshwater. Such dissimilarities in this parameter could be attributed to variations in the yield produced and the predicted yield losses under both irrigation water treatments.

Soybean crop

Predicted soybean yield under deficit irrigation

Soybean is one of the oil crops which is receiving attention from many researchers in Egypt. The germination stage is the most critical one as it requires an accurate irrigation regime. Irrigation with either too much or not enough water than needed will result in reducing seed germination and, thereby, lowering the final yield produced.

The predicted yield and the percent reductions under different deficit irrigation treatments for four successive growing seasons between 1998 and 2001 are presented in Table 4.28 and Figures 4.3 and 4.4.

The data indicate that, generally, under deficit irrigation treatments, the soybean crop followed a trend similar to those previously discussed for both cotton and clover. Taking the total irrigation as the reference, it is apparent that there is a reduction in the yield associated with a decrease in the volumes of irrigation water applied. This is also true for the yield data obtained during four growing seasons. Under irrigation with freshwater, the data show that irrigation with a water volume corresponding to 95% of the full irrigation treatment, (a 5% saving in water) did not result in any significant difference in the soybean yield – the values are more or less the same as those obtained under the full irrigation treatment.

This was also the case when the water saving was doubled from 5% to 10%. Under the 10% water saving treatment, the yield reduction during the four growing seasons averaged 2.2%, just 1.2% more losses in yield than were obtained with the 5% water saving treatment. When water saving was increased from 10% to 20%, the losses in the yield remained relatively low and did not exceed, on average, 8% with respect to that obtained under full irrigation.

In arid regions where water is the limiting factor to achieving food security, such results are satisfactory for soybean as well as the other crops studied at the Beni Sweif site. Under deficit irrigation techniques, the reductions in the amount of water applied result, to a certain extent, in a win-win situation. Not only is there potential for a large saving in water, but also a satisfactory yield production is maintained without any harmful losses.

The deficit irrigation treatments investigated showed a trend similar to those discussed for the freshwater treatments. They show slightly lower yields with the successive decreases in the volumes of irrigation water. However, for the four growing seasons investigated, the soybean yield, with a few exceptions, showed values which were always slightly lower than those obtained under the freshwater treatments.

In 1998, the yield obtained under irrigation with drainage water was, on average, nearly 10% more than that obtained under

Table 4.27. Predicted percent reduction in clover yield and CWU under different deficit irrigation treatments using fresh and drainage water during successive growing seasons from 1997-1998 to 2000- 2001 at Beni Sweif site.

Growing season 1997-1998

Irrigation treatment	Fresh water		Drainage water	
	Predicted yield reduction (%)	Predicted CWU reduction (%)	Predicted yield reduction (%)	Predicted CWU reduction (%)
Full irrigation	0	0	0	0
95% of total irrigation	3.20	0.44	1.86	0.18
90% of total irrigation	5.37	1.05	4.35	1.01
85% of total irrigation	7.10	2.10	7.87	2.82
80% of total irrigation	8.83	3.64	12.01	6.17

Growing season 1998-1999

Irrigation treatment	Fresh water		Drainage water	
	Predicted yield reduction (%)	Predicted CWU reduction (%)	Predicted yield reduction (%)	Predicted CWU reduction (%)
Total irrigation	0	0	0	0
95% of total irrigation	0	0	0	0
90% of total irrigation	1.14	0.05	0	0.10
85% of total irrigation	3.68	0.54	1.14	0.10
80% of total irrigation	6.85	1.91	3.60	0.54

Growing season 1999-2000

Irrigation treatment	Fresh water		Drainage water	
	Predicted yield reduction (%)	Predicted CWU Reduction (%)	Predicted yield reduction (%)	Predicted CWU reduction (%)
Total irrigation	0	0	0	0
95% of total irrigation	0.53	0.27	0.40	0.73
90% of total irrigation	2.24	1.02	1.60	0.50
85% of total irrigation	5.40	2.85	4.53	0.53
80% of total irrigation	8.96	6.30	7.32	2.94

Growing season 2000-2001

Irrigation treatment	Fresh water		Drainage water	
	Predicted yield reduction (%)	Predicted CWU reduction (%)	Predicted yield reduction (%)	Predicted CWU reduction %()
Total irrigation	0	0	0	0
95% of total irrigation	3.63	1.17	3.87	2.60
90% of total irrigation	4.44	1.87	4.00	2.92
85% of total irrigation	6.06	3.81	5.03	4.29
80% of total irrigation	9.50	7.29	8.13	7.11

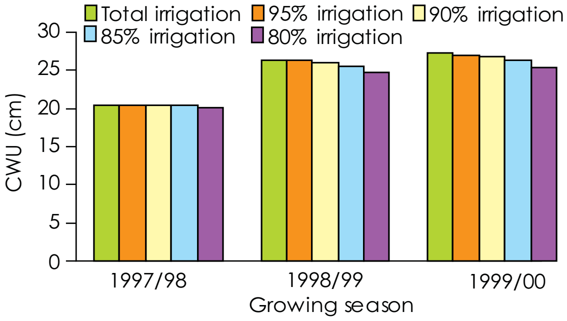

Figure 4.1. The CWU for clover planted at Beni Sweif under different fresh water deficit irrigation treatments for three growing seasons.

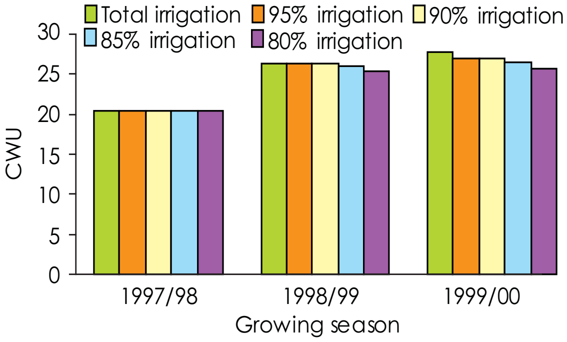

Figure 4.2. The CWU for clover planted at Beni Sweif under different drainage water deficit irrigation treatments for three growing seasons.

freshwater irrigation, whereas it amounted to just 85% of the freshwater yield in the next two successive growing seasons, 1999 and 2000. In 2001 it drastically dropped to an average value nearly 50% lower than that obtained with freshwater. This could be attributed to changes in the EC values of the drainage water from one crop season to the next

Predicted water use of soybean under deficit irrigation

The predicted reductions in soybean yields and water used under different deficit irrigation treatments as compared to the full irrigation treatments are presented in Figures 4.5 and 4.6 and Table 4.29. They show the reductions in CWU for soybean planted under fresh and drainage water deficit irrigation.

The data show that under deficit irrigation, gradually decreasing the volume of water applied affected the CWU of soybean, gradually decreasing its value with respect to that when full irrigation was practiced. This holds true under irrigation with freshwater as well as with drainage water. However, under drainage water practices and for the four cropping seasons considered, the reductions in CWU as percentages of the full irrigation treatment had values that, in general, were lower than the ones predicted for irrigation under fresh water. This could be explained by the fact that under irrigation with drainage water, the percent reductions in yield were relatively lower than the ones obtained when irrigating with freshwater, and this was the opposite of that concerning water use.

Wheat

Predicted wheat yield under deficit irrigation

The predicted wheat yield for four successive growing seasons (between 1998-1999 and 2000-2001) under different fresh and drainage water irrigation treatments, and its reduction, expressed as a percentage of the yield produced under a total irrigation treatment, are presented in Table 4.30.

The data presented in Table 4.30 clearly show that wheat is one of the crops among those studied that can be grown successfully with smaller volumes of water applied without it having a significant effect on the yield. The data obtained under the different deficit irrigation treatments investigated for the successive growing seasons show that irrigation with volumes of water 30% less than that used for full irrigation gave an average yield of 5.52 t/ha. This compares favorably to the average yield of 5.88 t/ha for the full

Table 4.28. Predicted yield and percent reduction for soybean grown under different deficit irrigation treatments for four successive growing seasons, 1998-2001.

Growing season 1998

Irrigation treatment	Fresh water irrigation		Drainage water irrigation	
	Predicted yield (t/ha)	Reduction (%)	Predicted yield (t/ha)	Reduction (%)
Total irrigation	1.20	0	1.33	0
95% of total irrigation	1.19	0.83	1.32	0.75
90% of total irrigation	1.17	2.50	1.29	3.01
85% of total irrigation	1.15	4.17	1.26	5.26
80% of total irrigation	1.12	6.67	1.21	9.02

Growing season 1999

Irrigation treatment	Fresh water irrigation		Drainage water irrigation	
	Predicted yield (t/ha)	Reduction (%)	Predicted yield (t/ha)	Reduction (%)
Total irrigation	2.24	0	1.77	0
95% of total irrigation	2.22	0.89	1.75	1.13
90% of total irrigation	2.16	3.57	1.72	2.82
85% of total irrigation	2.07	7.59	1.68	5.08
80% of total irrigation	2.04	8.93	1.62	8.47

Growing season 2000

Irrigation	Fresh water irrigation		Drainage water irrigation	
	Predicted yield (t/ha)	Reduction (%)	Predicted yield (t/ha)	Reduction (%)
Total irrigation	1.70	0	1.54	0
95% of total irrigation	1.69	0.59	1.53	0.65
90% of total irrigation	1.67	1.76	1.50	2.60
85% of total irrigation	1.63	4.12	1.47	4.55
80% of total irrigation	1.58	7.06	1.43	7.14

Growing season 2001

Irrigation treatment	Fresh water irrigation		Drainage water irrigation	
	Predicted yield (t/ha)	Reduction (%)	Predicted yield (t/ha)	Reduction (%)
Total irrigation	1.67	0	0.86	0
95% of total irrigation	1.65	1.20	0.85	1.16
90% of total irrigation	1.61	3.59	0.83	3.49
85% of total irrigation	1.58	5.39	0.82	4.65
80% of total irrigation	1.53	8.38	0.80	6.98

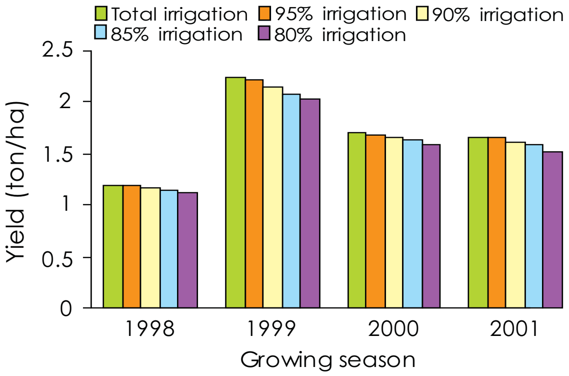

Figure 4.3. Soybean yields under different fresh water deficit irrigation for four growing seasons at Beni Sweif.

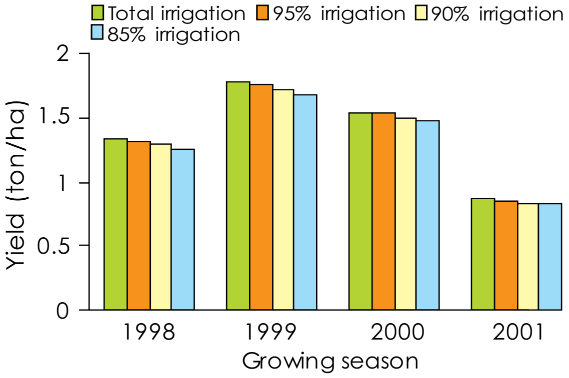

Figure 4.4. Soybean yields under different drainage water deficit irrigation for four growing seasons at Beni Sweif.

irrigation treatment. and represents a 6% reduction on average. Furthermore, the yield data, when irrigation was practiced with 80% of the full irrigation volumes, show no significant reduction in yield – the values were nearly equal to those obtained under full irrigation and represent an average yield loss of around 2.3%.

Such data should be translated into actions to be implemented on the ground. Egypt, at the national level, produces only 50% of the wheat required to satisfy its needs, while the other 50% is imported from abroad. The annually increasing demands for wheat throw increasing demands on the foreign

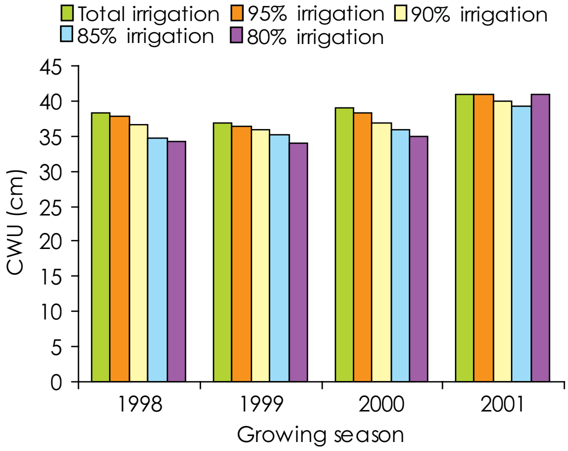

Figure 4.5. The CWU for soybean planted at Beni Sweif under different fresh water deficit irrigation treatments for four growing seasons.

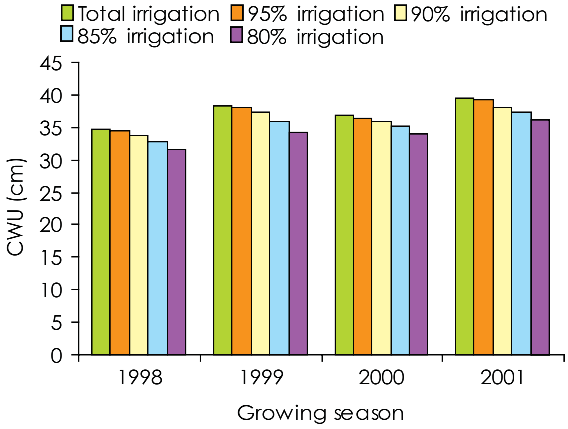

Figure 4.6. The CWU for soybean planted at Beni Sweif under different drainage water deficit irrigation treatments for four growing seasons.

currency resources of the country to pay for this imported supply. Such a situation creates serious problems, notably and negatively affecting not only the national income, but, equally, the economic and social development programs.

A sustainable solution to the problem lies in increasing national wheat production to reduce the relatively high import costs

Table 4.29. Percent reduction in predicted yield and CWU for soybean grown under different deficit irrigation treatments in four growing seasons between 1998 and 2001, at Beni Sweif site.

Growing season 1998

Irrigation treatment	Fresh water		Drainage water	
	Predicted yield reduction (%)	Predicted WU reduction (%)	Predicted yield reduction (%)	Predicted WU reduction (%)
Total irrigation	0	0	0	0
95% of total irrigation	0.83	1.02	0.75	1.01
90% of total irrigation	2.50	2.46	3.01	2.94
85% of total irrigation	4.17	4.52	5.26	5.70
80% of total irrigation	6.67	7.66	9.02	9.01

Growing season 1999

Irrigation treatment	Fresh water		Drainage water	
	Predicted yield reduction (%)	Predicted WU reduction (%)	Predicted yield reduction %	Predicted WU reduction (%)
Total irrigation	0	0	0	0
95% of total irrigation	0.89	1.10	1.13	0.73
90% of total irrigation	3.57	4.08	2.82	2.32
85% of total irrigation	7.59	9.24	5.08	6.24
80% of total irrigation	8.93	10.40	8.47	10.86

Growing season 2000

Irrigation treatment	Fresh water		Drainage water	
	Predicted yield reduction (%)	Predicted WU reduction (%)	Predicted yield reduction (%)	Predicted WU reduction (%)
Total irrigation	0	0	0	0
95% of total irrigation	0.59	1.17	0.65	1.17
90% of total irrigation	1.76	2.56	2.60	2.77
85% of total irrigation	4.12	4.44	4.55	4.70
80% of total irrigation	7.06	7.40	7.14	7.52

Growing season 2001

Irrigation treatment	Fresh water		Drainage water	
	Predicted yield reduction (%)	Predicted WU reduction (%)	Predicted yield reduction (%)	Predicted WU reduction (%)
Total irrigation	0	0	0	0
95% of total irrigation	1.20	1.94	1.16	0.94
90% of total irrigation	3.56	5.50	3.49	3.84
85% of total irrigation	5.39	8.00	4.65	5.71
80% of total irrigation	8.38	10.53	6.98	8.42

Table 4.30. Wheat yield under different deficit irrigation treatments in the growing seasons 1998-2001 at Beni Sweif site.

Growing season 1998

Irrigation treatment	Fresh water irrigation		Drainage water irrigation	
	Predicted yield (t/ha)	Reduction (%)	Predicted yield (t/ha)	Reduction (%)
Total irrigation	5.28	0	5.23	0
90% of total irrigation	5.27	0.19	5.22	0.19
85% of total irrigation	5.26	0.38	5.19	0.76
80% of total irrigation	5.16	2.27	5.16	1.34
70% of total irrigation	5.07	3.98	5.07	3.06

Growing season 1999

Irrigation treatment	Fresh water irrigation		Drainage water irrigation	
	Predicted yield (t/ha)	Reduction (%)	Predicted yield (t/ha)	Reduction (%)
Total irrigation	5.73	0	4.73	0
90% of total irrigation	5.72	0.17	4.73	0
85% of total irrigation	5.68	0.87	4.72	0.21
80% of total irrigation	5.68	0.87	4.71	0.42
70% of total irrigation	5.52	3.66	4.61	2.54

Growing season 2000

Irrigation treatment	Fresh water irrigation		Drainage water irrigation	
	Predicted yield (t/ha)	Reduction (%)	Predicted yield (t/ha)	Reduction (%)
Total irrigation	5.73	0	6.31	0
90% of total irrigation	5.71	0.35	6.30	0.16
85% of total irrigation	5.69	0.70	6.26	0.79
80% of total irrigation	5.59	2.44	6.19	1.90
70% of total irrigation	5.31	7.33	5.89	6.66

Growing season 2001

Irrigation treatment	Fresh water irrigation		Drainage water irrigation	
	Predicted yield (t/ha)	Reduction (%)	Predicted yield (t/ha)	Reduction (%)
Total irrigation	6.79	0	6.52	0
90% of total irrigation	6.70	1.33	6.45	1.07
85% of total irrigation	6.65	2.06	6.36	2.45
80% of total irrigation	6.53	3.83	6.27	3.83
70% of total irrigation	6.18	8.98	5.97	8.44

which the country is incurring to meet the shortage in local wheat production.

For Egypt, wheat is a strategic crop, which provides bread – the essential food to feed the increasing population. In this regard, the questions which are now under continuous debate are, “At the national level, can Egypt satisfy its needs for wheat? And if so, what tools and means need to be implemented to achieve such a goal?” The answer to these questions is not easy. Theoretically, the possibility exists, but technically it is not an easy process. However, through effective work, appropriate planning, the introduction of new technologies, improvement of the capacities of national and local institutions, and by developing and updating people’s skills, what is now a questionable objective, will be, in the long-term, a realistic one.

The data obtained in this long-term program favors the idea that, in the long run, a good opportunity to increase wheat production does exist. Implementing this opportunity will gradually reduce the gap between the amounts of wheat produced and consumed locally.

It is well recognized that for most arid regions, water is the main limiting factor to increasing production of most crops, including wheat. However, wheat, as compared with the previously studied crops, seems to be more tolerant to water-stress conditions. This is quite evident from the data. Hence, irrigating wheat with volumes of water corresponding to about two-thirds of that representing its actual water requirement will result in a yield nearly similar to that obtained under full irrigation. On average the yield loss would be around 5%. This means that with less water, we can have virtually the same production. Such data have been obtained under a 30% water saving on the volume traditionally applied. This again indicates that by increasing the water saving from 30% to 40%, and even up to 50%, it is possible to achieve a satisfactory wheat production without any notable losses in yield.

As can be seen, we can have more or less the same wheat yield with water savings ranging from 30% up to 50% of the total water requirement of the crop. Combine this with the new wheat varieties, identify the correct irrigation scheduling to be implemented at the different growth stages – enabling tools and means that should be effectively and properly used – and support these efforts with the needed research, and we should be able to bridge the seriously increasing gap between wheat supply and demand.

Predicted water use by wheat under deficit irrigation

In comparison with the other crops studied, wheat showed more tolerance to water stress conditions under deficit irrigation technique, even when the amount of water applied was reduced up to 30%. The reductions in predicted yields as well as those in CWU under the investigated deficit irrigation treatments are shown in Table 4.31. The CWU for wheat planted under different fresh and drainage water deficit irrigation treatments are shown in Figures 4.7 and 4.8.

As shown in Table 4.30 and Figures 4.7 and 4.8, it is quite apparent that under the different deficit irrigation treatments investigated, the reduction in the CWU with respect to the full irrigation treatment followed a trend similar to that characterizing the losses in wheat production. The lower the volume of applied water; the higher is the reduction in both the CWU of wheat and its yield.

This holds true for irrigation with both fresh and drainage water. However, for the deficit drainage water irrigation treatments, the percent reductions in the CWU were slightly smaller than those predicted under the freshwater irrigation treatments. This is clearly seen when comparing the percent reductions in CWU in the 1998 and 1999 growing seasons with those of the 2000 and 2001 seasons and, particularly, those achieved under the relatively high 30% water saving treatments. Under the deficit irrigation

Table 4.31. Percent reductions in wheat production and CWU under different deficit irrigation treatments during successive growing seasons (1998-2001) at Beni Sweif site.

Growing season 1998

Irrigation treatment	Fresh water irrigation		Drainage water irrigation	
	Predicted yield reduction (%)	Reduction in CWU (%)	Predicted yield reduction (%)	Reduction in CWU (%)
Total irrigation	0	0.29	0	0
90% of total irrigation	0.19	0.44	0.19	0.32
85% of total irrigation	0.38	2.36	0.76	0.95
80% of total irrigation	2.27	4.14	1.34	1.54
70% of total irrigation	3.98	0	3.06	3.90

Growing season 1999

Irrigation treatment	Fresh water irrigation		Drainage water irrigation	
	Predicted yield reduction (%)	Reduction in CWU (%)	Predicted yield reduction (%)	Reduction in CWU (%)
Total irrigation	0	0	0	0
90% of total irrigation	0.17	0.26	0.00	0.02
85% of total irrigation	0.87	0.81	0.21	0.14
80% of total irrigation	0.87	0.96	0.42	0.38
70% of total irrigation	3.66	3.72	2.54	2.63

Growing season 2000

Irrigation treatment	Fresh water irrigation		Drainage water irrigation	
	Predicted yield reduction (%)	Reduction in CWU (%)	Predicted yield reduction (%)	Reduction in CWU (%)
Total irrigation	0	0	0	0
90% of total irrigation	0.35	0.56	0.10	0.25
85% of total irrigation	0.70	1.13	0.70	1.08
80% of total irrigation	2.44	3.25	1.90	2.53
70% of total irrigation	7.33	9.54	6.66	8.82

Growing season 2001

Irrigation treatment	Fresh water irrigation		Drainage water irrigation	
	Predicted yield reduction (%)	Reduction in CWU (%)	Predicted yield reduction (%)	Reduction in CWU (%)
Total irrigation	0	0	0	0
90% of total irrigation	1.33	1.55	1.07	1.55
85% of total irrigation	2.06	2.95	2.45	3.53
80% of total irrigation	3.83	5.45	3.83	5.45
70% of total irrigation	8.98	12.24	8.44	11.52

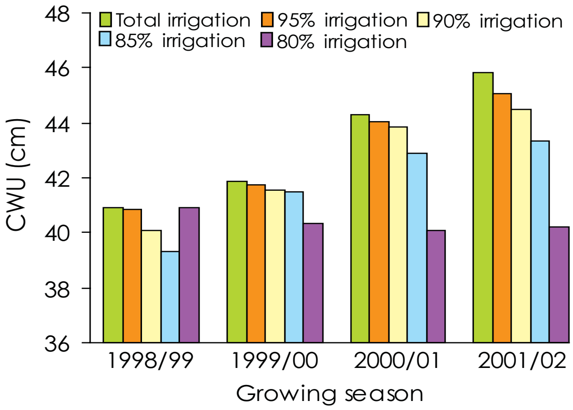

Figure 4.7. The CWU for wheat under different fresh water deficit irrigation treatments during four growing seasons at Beni Sweif.

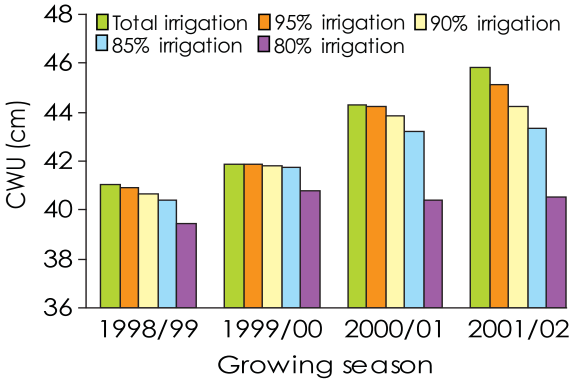

Figure 4.8. The CWU for wheat under different drainage water deficit irrigation treatments during four growing seasons at Beni Sweif.

treatments corresponding to 70% of full irrigation, the reductions in CWU for the 2000 and 2001 cropping seasons was between three and four times greater than those predicted in the previous growing seasons of 1998 and 1999. This holds true for irrigation with fresh as well as drainage water. Such reductions in CWU values with the change from one cropping season to another could be attributed to the changes in the wheat yield from one season to the next. However, a difference in consumptive water use arising from variations in the irrigation water quality could be due to the influence exerted by the drainage water on yield production, with these values being slightly lower than those obtained when irrigating with freshwater. This again confirms the existence of a strong relationship between yield and the CWU under irrigation with different volumes of water and waters of different qualities.

Faba bean

Faba bean is one of the essential food legumes of Egypt. It is a popular food for Egyptians and the amounts consumed are increasing from year to year – a result of the high rate of increase in population. From the 1980s to the 1990s, Egypt achieved self sufficiency in this crop. However, Egypt has for some years been, and is now, experiencing a big gap between demand for and production of faba bean. This shortage in production has to be addressed by imports, which adds a heavy burden to the country's national budget. Government policy is to increase the production of several essential crops, particularly wheat and faba bean, where consumption is notably exceeding production.

An appropriate way to overcome such a gap is to increase crop production to meet the increasing demand. This is not an easy task. We have only few approaches to follow. An increase in crop production could be realized by augmenting the irrigated area. However, in the dry region, the shortage of available water and productive lands are major limiting factors impeding such a strategy.

An approach to be followed, without the need for additional water supplies, is by increasing the crop water productivity. That can be achieved by increasing the 'crop per drop' – increasing the yield with the same amount of water. Improving crop water productivity could also be achieved by implementing deficit irrigation techniques through which we can have more or less the same yield using less water for irrigation. Water allocated to agriculture amounts to nearly 80% or more of the total available freshwater. Using deficit irrigation, there is the high potential to save ample amounts of irrigation water.. However, implementing deficit irrigation successfully on a large scale requires adequate, up-to-date knowledge based on experimental results and research findings in order to find an appropriate irrigation regime to be followed which provides, on the one hand, a satisfactory yield and, on the other, a significant saving of water.

Predicted yield of faba bean under deficit irrigation

The predicted yields (t/ha) under the different fresh and drainage water deficit irrigation treatments investigated, and their percent reductions in the three successive cropping seasons (from 1998-1999 to 2001-2002) at the Beni Sweif site, are given in Figures 4.9 and 4.10 and Table 4.32.

The data show that the gradual decrease in the volume of water applied resulted in a gradual reduction in the faba bean yield. However, under each deficit irrigation treatment, even that where irrigation was undertaken with a water volume 20% lower than that for full irrigation, the faba bean crops showed yields very similar to that obtained under full irrigation – the average yield reduction did not exceed 5% over all cropping seasons. This statement also holds true under irrigation with drainage water. However, the faba bean yields under the drainage water irrigation treatments showed values slightly lower than those when freshwater was used. Such not significant differences between faba bean yields under drainage water irrigation and freshwater irrigation, is evidence that faba bean can be successfully grown without any drastic drop in its yield, using drainage water of a salinity level that the crop can tolerate. In this case, using deficit irrigation techniques and irrigating with drainage water is a win-win game providing, on the one hand, a saving of freshwater and, on the other, a reduction in the degree of salt accumulation within the active root zone.

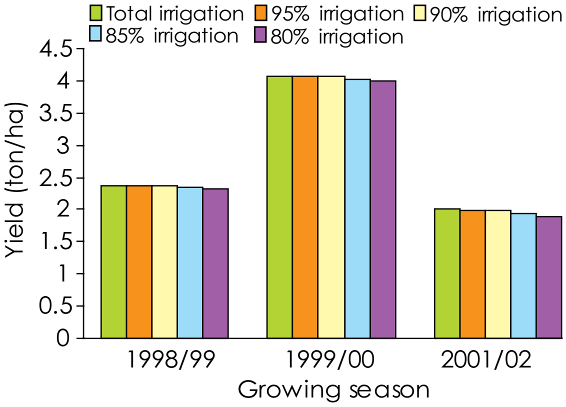

Figure 4.9. Faba bean yields under different fresh water deficit irrigation treatments for three growing seasons at Beni Sweif.

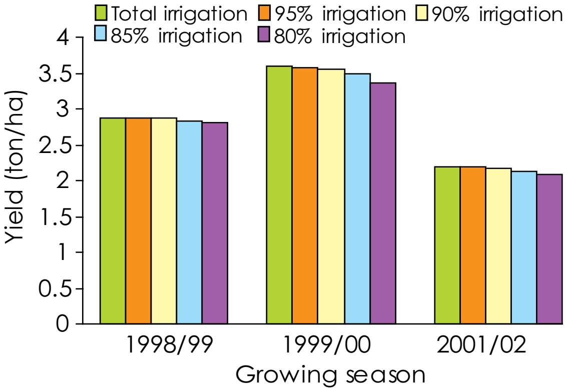

Figure 4.10. Faba bean yields under different drainage water deficit irrigation treatments for three growing seasons at Beni Sweif.

It is of special interest here that irrigation with a freshwater volume corresponding to 80% of the full irrigation requirement does not result in any drastic drop in yield. This suggests that it might be possible to grow a faba bean crop with a satisfactory yield with greater savings in the amount of water used – from 20% to 30% less, perhaps up to 40% less or much more. However, this has to be studied experimentally.

This was the main objective of the experimental work carried out during the course of the Project.

Table 4.32. Predicted faba bean yield under different irrigation treatments at the Beni Sweif site.

Growing season 1998-1999

Irrigation treatment	Fresh water irrigation		Drainage water irrigation	
	Predicted yield (t/ha)	Reduction (%)	Predicted yield (t/ha)	Reduction (%)
Total irrigation	2.88	0	2.37	0
95% of total irrigation	2.88	0	2.37	0
90% of total irrigation	2.87	0.35	2.37	0
85% of total irrigation	2.84	1.39	2.35	0.84
80% of total irrigation	2.81	2.43	2.33	1.69

Growing season 1999-2000

Irrigation treatment	Fresh water irrigation		Drainage water irrigation	
	Predicted yield (t/ha)	Reduction (%)	Predicted yield (t/ha)	Reduction (%)
Total irrigation	3.60	0	4.08	0
95% of total irrigation	3.58	0.56	4.07	0.25
90% of total irrigation	3.56	1.11	4.06	0.49
85% of total irrigation	3.49	3.06	4.03	1.23
80% of total irrigation	3.36	6.67	3.99	2.21

Growing season 2001-2002

Irrigation treatment	Fresh water irrigation		Drainage water irrigation	
	Predicted yield (t/ha)	Reduction (%)	Predicted yield (t/ha)	Reduction (%)
Total irrigation	2.20	0	2.00	0
95% of total irrigation	2.19	0.45	1.99	0.50
90% of total irrigation	2.17	1.36	1.98	1.00
85% of total irrigation	2.13	3.18	1.95	2.50
80% of total irrigation	2.08	5.45	1.90	5.00

Onions

Predicted onion yield under deficit irrigation

The predicted onion yield and its percent reductions under different deficit irrigation treatments are presented in Table 4.33 and Figures 4.11 and 4.12.

The data in Table 4.33 indicate that onion could be grown successfully under deficit irrigation practices. For all growing seasons, irrigation with 80% of the full irrigation requirement (a 20% saving in water) did not result in any significant differences in the onion yields, they were more or less the same as those achieved under full irrigation.

The differences in onion production between a full irrigation treatment and the highest deficit irrigation one did not exceed, on average, 2% for all the growing seasons. This also holds true for irrigation

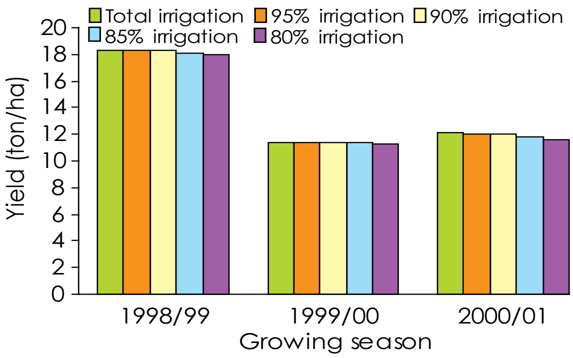

Figure 4.11 Onion yields under different fresh water deficit irrigation treatments for three growing seasons at Beni Sweif.

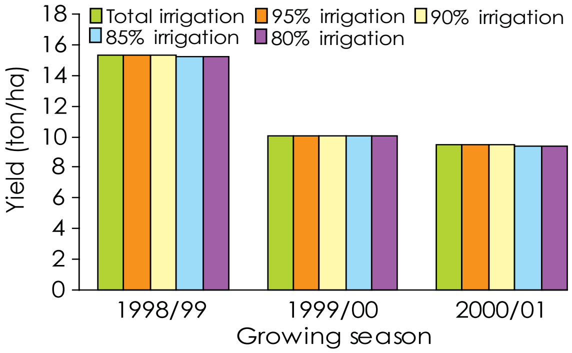

Figure 4.12. Onion yields under different drainage water deficit irrigation treatments for three growing seasons at Beni Sweif.

under fresh and drainage water treatments. However, in comparison with the crops discussed previously, it is quite clear that onion are more affected. Looking at the yield under full irrigation, it can be seen that for the freshwater treatment, the yield was, on average, nearly 17% higher than the yield where drainage water irrigation was used. This was also the case under the different deficit irrigation treatments investigated. The yield under the drainage water irrigation treatments was always lower than that obtained under the similar fresh water one. Such findings could be attributed to the high sensitivity of onion to the salinity level of the irrigation water.

The data for the predicted yields under the different deficit irrigation treatments (Table 4.33), show that under the drainage water irrigation treatments the reductions in the onion yield, compared that achieved when providing the full water requirement, were relatively small, amounting to just one-half, or in some cases, one-third or even less. Such data indicate that the onion crop is more resistant to water stress rather than to salt stress.

As previously mentioned, the minimum reduction in the onion yield due to deficit irrigation with fresh water, amounted to just 2% of that achieved under full irrigation. This was accompanied by a 20% saving in water, which, again, confirms that onion can tolerate water stress conditions. Thus onion can be grown successfully without any drastic drop in yield using volumes of water below that currently used, which will lead to further water savings.

4.3.3 Model validation using current experimental field data

Yield-Stress model validation under the application of there was a notable total irrigation amounts

The data below show no or very little stress, because the CWU is essentially not affected. This would not be considered as a deficit unless reduction in CWU (i.e., evapotranspiration).

For El-Monofia site, the percent difference between the measured and predicted yields was less than 0.5 (Table 4.34). The highest difference in water use was obtained for the first farm.

For El-Serw site, there was no difference between the measured and predicted yields (Table 4.35). This is an indication that the amount of irrigation water applied was enough to meet the evapotranspiration demand. Furthermore, the difference between measured and predicted water use was less than 0.5%, except for Farm 4, where it was 1.63% (Table 2.35).

Table 4.33: Predicted onion yield and its percent reduction under different deficit irrigation treatments during the successive cropping seasons 1998-2002 at Ben Sweif site.

Growing season 1998-1999

Irrigation treatment	Fresh water irrigation		Drainage water irrigation	
	Predicted yield (t/ha)	**Reduction (%)**	**Predicted yield (t/ha)**	**Reduction (%)**
Total irrigation	18.33	0	15.30	0
95% of total irrigation	18.33	0	15.29	0.07
90% of total irrigation	18.29	0.22	15.28	0.13
85% of total irrigation	18.12	1.15	15.26	0.26
80% of total irrigation	18.02	1.69	15.24	0.39

Growing season 1999-2000

Irrigation treatment	Fresh water irrigation		Drainage water irrigation	
	Predicted yield (t/ha)	**Reduction (%)**	**Predicted yield (t/ha)**	**Reduction (%)**
Total irrigation	11.42	0	10.06	0
95% of total irrigation	11.42	0	10.06	0
90% of total irrigation	11.41	0.09	10.05	0.10
85% of total irrigation	11.39	0.26	10.04	0.20
80% of total irrigation	11.31	0.96	10.01	0.50

Growing season 2000-2001

Irrigation treatment	Fresh water irrigation		Drainage water irrigation	
	Predicted yield (t/ha)	**Reduction (%)**	**Predicted yield (t/ha)**	**Reduction (%)**
Total irrigation	12.09	0	9.48	0
95% of total irrigation	12.07	0.17	9.47	0.11
90% of total irrigation	12.00	0.74	9.45	0.32
85% of total irrigation	11.86	1.90	9.39	0.95
80% of total irrigation	11.60	4.05	9.35	1.37

Yield-Stress model validation under deficit irrigation

The model was used to predict wheat yields following deduction of about 20% of the total irrigation water at El-Monofia site (Table 4.36). The predicted wheat yield was close to the measured one for two of the three farms. The root mean square error (RMSE) was 0.048 and Willmott index of agreement was 0.977. Predicted water use was also close to the measured water use, except for the third farm. The RMSE was 0.040 and Willmott index of agreement was 0.999. Regression analysis between measured and predicted wheat yields at El-Monofia site had a significant linear relationship ($P < 0.05$), with equation

$$y = -2.278 + 1.278x \ (R^2 = 0.991).$$

For El-Serw site, there was good agreement between the measured and predicted wheat yields and the water use at three of the four farms. The percent difference between the measured and predicted yields and the water use was high for the fourth farm. The RMSE for the yield was 0.039 and that for water use was 0.040. The Willmott index of agreement was 0.999 for both yield and water use (Table 4.37). A statistically significant linear relationship ($P < 0.01$) between the measured and predicted wheat yields at El-Serw site was found with a linear regression equation

$$y = 0.129 + 0.978x (R^2 = 0.999).$$

Tested scenario of deficit irrigation

It was of special interest to use the Yield-Stress model to predict wheat yield under a deficit irrigation treatment using 30% less

Table 4.34. Measured versus predicted wheat yield and CWU at El-Monofia site.

Farm	Yield (t/ha)		Difference (%)	CWU (m^3)		Difference (%)
	Measured	Predicted		Measured	Predicted	
Farm 1	9.43	9.41	0.21	32.15	31.58	1.77
Farm 2	7.61	7.61	0	31.22	31.15	0.22
Farm 3	7.75	7.74	0.13	32.15	31.90	0.78

Note: CWU – consumptive water use.

Table 4-35. Measured versus predicted wheat yield and CWU at El-Serw site.

Farm	Yield (t/ha)		Difference (%)	CWU (m^3)		Difference (%)
	Measured	Predicted		Measured	Predicted	
Farm 1	5.60	5.60	0	31.86	31.99	0.41
Farm 2	5.25	5.25	0	31.28	31.42	0.45
Farm 3	4.55	4.55	0	33.74	33.62	0.36
Farm 4	6.20	6.20	0	34.38	34.94	1.63

Note: CWU – consumptive water use.

Table 4.36. Measured versus predicted wheat yield and CWU at El-Monofia site after deducting 20% of the total irrigation water.

Farm	Yield (t/ha)		Difference (%)	CWU (m^3)		Difference (%)
	Measured	Predicted		Measured	Predicted	
Farm 1	9.43	9.18	2.65	30.54	30.68	0.45
Farm 2	7.39	7.45	0.81	30.60	30.99	1.29
Farm 3	6.64	7.07	6.48	30.54	28.86	5.51
RMSE	0.048			0.040		
Willmott index	0.977			0.999		

Note: CWU – consumptive water use.

Table 4.37. Measured versus predicted wheat yield and CWU at El-Serw site after deducting 25% of the total irrigation water.

Farm	Yield (t/ha)		Difference (%)	CWU (m^3)		Difference (%)
	Measured	Predicted		Measured	Predicted	
Farm 1	5.50	5.50	0	30.27	31.22	3.15
Farm 2	5.15	5.11	0.78	29.72	30.26	1.83
Farm 3	4.40	4.37	0.68	32.05	31.98	0.23
Farm 4	5.70	6.05	6.14	32.14	33.94	5.58
RMSE	0.039			0.040		
Willmott index	0.999			0.999		

Note: CWU – consumptive water use.

water than that used for full irrigation. The model was used at El-Monofia site (Table 4.38-A). The value of the yield of the third farm was excluded from the prediction because the percent difference between the measured and predicted wheat yields under deficit irrigation was high. Therefore, only the first two farms were included in Table 4.38-A. The results in that table indicate that the wheat yield at that site might be reduced by 5.40% if the amount of irrigation water applied was reduced by 30%. At El-Serw site, the yield of the fourth farm was excluded from the analysis. The results in Table 4.38-B show that by saving 30% of the total applied irrigation water, the wheat yield would be reduced by 5.94%.

The data indicate that the measured wheat production varied greatly from one site to another. At El-Monofia site, the measured yield had an average value nearly 40% higher than that obtained at the Damietta site. For both sites, the experiments were carried out during the same growing season using the same irrigation regime and, therefore, such notable variation from on site to another could be attributed to variation in soil productivity as well as to differences in climatic factors.

In addition, the data showed the similarity between the measured and the predicted wheat yield at both sites, indicating the validity of the model.

Table 4.38-A. Measured and predicted wheat yield at Monofia site, 2005-2006 growing season.

Farm	Yield (t/ha)		Reduction (%)
	Measured	Predicted	
Farm 1	9.43	8.92	5.41
Farm 2	7.61	7.20	5.39
Average	8.52	8.06	5.40

Table 4-38-B. Measured and predicted wheat yield at Damietta site, 2005-2006 growing season.

Farm	Yield (t/ha)		Reduction (%)
	Measured	Predicted	
Farm 1	5.60	5.14	8.20
Farm 2	5.25	5.00	4.76
Farm 3	4.55	4.33	4.84
Average	5.13	4.82	5.94

It can be seen that saving 30% of the water applied resulted in yield losses not exceeding 6%. This is a very promising result, and draws attention to the high potential for water savings, amounting to 40% or 50%

of the full irrigation volume, when cropping wheat. However, care must be taken to avoid water stress of the crop during the sensitive growth stages. In this regard, much research work and many studies have been carried out by several workers and they generally came to the conclusion that for wheat, the germination and seedling stages are very sensitive to water shortage and that seed germination failure will be reflected in the final yield produced. Their data, also, indicated that both flowering and seed filling are crucial stages where any shortage of water will result in a drastic drop in wheat production. Accordingly, increasing the amount of water saved under wheat cropping and obtaining a satisfactory production is not difficult. What is needed is to set up an appropriate irrigation schedule that will fulfill the water requirement of the wheat growth stages according to their sensitivity and/or their resistance to water stress conditions.

4.3.4. Using the Yield-Stress model as an irrigation management tool

El-Monofia site

At El-Monofia site, the second farm was chosen because there was plenty of readily available water at the root zone after the fifth and sixth irrigations (Figure 4.13).

Therefore, the amounts of these two irrigations were reduced (Figure 4.14) and this saved around 22% of the water applied and the resulting yield loss was 0.13% (Table 4.39).

El-Serw site

Similar results were obtained for the third farm at El-Serw site. This farm was selected because there was also plenty of readily available water at the root zone after the fourth, fifth, and sixth irrigations (Figure 4.15). For that reason, the amounts of these three irrigations was reduced (Figure 4.16) leading to an approximate 24% saving in the amount of water applied with no yield loss (Table 4.39).

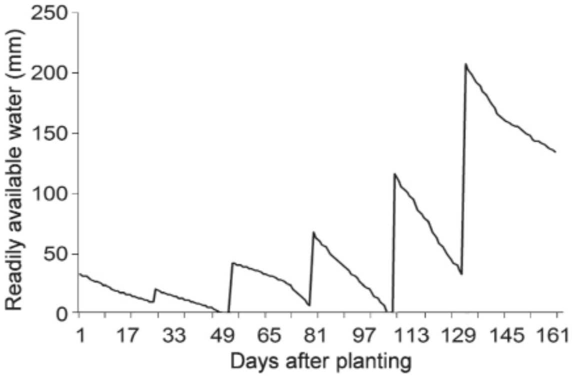

Figure 4.13. Depletion of the readily available water at the root zone after the application of each individual irrigation for wheat under the total irrigation amount (El-Monofia, Farm 2).

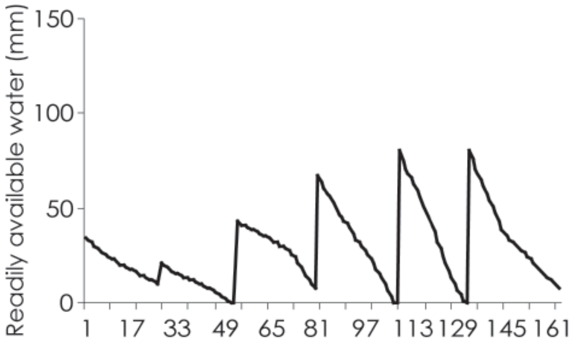

Figure 4.14. Depletion of the readily available water at the root zone after the application of each individual irrigation for wheat at 78% of the total irrigation amount (El-Monofia, Farm 2).

Table 4.39. Amount of irrigation water saved and corresponding reduction in yield at the three sites

Site	Amount of irrigation water saved (%)	Yield reduction (%)
Beni Sweif: 1999-2000	21	0
El-Monofia: farm 2	22	0.13
El-Serw: Farm 3	24	0

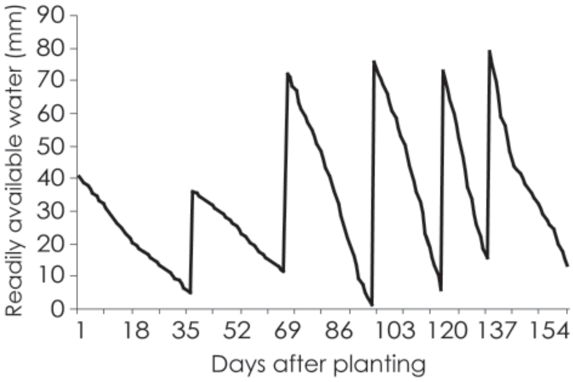

Figure 4.15. Depletion of the readily available water at the root zone after the application of each individual irrigation for wheat grown under the total irrigation amount (El-Serw, Farm 3).

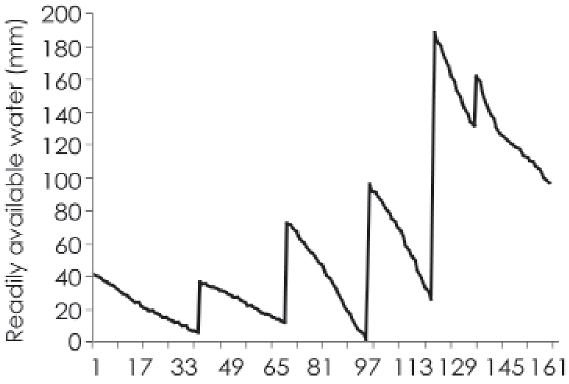

Figure 4.16. Depletion of the readily available water at the root zone after the application of each individual irrigation for wheat grown under the total irrigation amount (El-Serw, farm 3).

The above results suggest that using the model when studying the depletion of readily available water could be very helpful in saving irrigation water and in reducing unnecessary water losses, while maintaining a minimal yield reduction. At El-Monofia and El-Serw sites, around 22% and 24% of the total amount of irrigation water applied was saved with very low or no yield losses.

4.3.5 Yield-Stress model validation under salinity stress

Under salinity stress and applying the total irrigation amounts, the model overestimated wheat yield by 1.11% for Farm 1 and 0.60% for Farm 2. Under deficit irrigation, the model over predicted wheat yield for Farm 1 by 0.96%, while it under predicted the yield of Farm 2 by 1.52%. This result implied that the model can predict wheat yield under salinity stress and under salinity and water stresses (Table 4.40).

4.3.6 Tested deficit irrigation scenario

The measured and predicted wheat yields at the Damietta site using drainage water with a high level of salinity at volumes 30% lower than that for full irrigation are given in (Table 4.41).

The data presented indicate that deficit irrigation with drainage water in an amount equal to that of the fresh water does not notably affect the yield; the average yield losses were around 23% when compared with the yield obtained using the same amount of freshwater. The percent

Table 4.40. Measured versus predicted wheat yield under full and deficit irrigation.

Farm	Yield under full irrigation (t/ha)		Difference (%)	Yield under deficit irrigation (t/ha)		Difference (%)
	Measured	Predicted		Measured	Predicted	
Farm 1	4.52	4.57	1.11	4.15	4.19	0.96
Farm 2	3.35	3.37	0.60	3.30	3.25	1.52

Table 4.41. Measured and predicted wheat yield at Damietta, 2005-2006 growing season.

Farm	Yield (t/ha)		Reduction (%)
	Measured	Predicted	
Farm 1	4.52	3.77	16.59
Farm 2	3.35	2.91	13.13
Average	3.94	3.34	14.86

reductions in wheat yield under drainage irrigation was nearly 3 times greater than those when freshwater was used.

Such notable reductions in yield under drainage irrigation could be explained by the fact that irrigation was practiced with 70% of the total required volume of water. Therefore, the subsequent successive irrigations resulted in a rapid accumulation of salts in the active root zone to a level that the wheat could not tolerate. Hence, during the experiment, leaching was completely absent and this could be the reason behind such an excessive reduction in wheat yield.

4.4 Summary and conclusions

Over the last two decades, models have become a major research tool for resource management. In arid regions, water scarcity on the one hand, and the important role of water conservation in the agricultural sector on the other, are driving drastic changes in the ways we use and manage water resources. Saving water in the irrigation sector through improvement of on-farm water use efficiency is now a must, and it requires the exploration of different water management practices. However, this could be an expensive and a long drawn out process. By using simulation models it could be easy to predict the effect on the yield of the primary crops cultivated under irrigation with less volumes of water than the full irrigation requirement.

In the different regions of Egypt, irrigation management can be done by modeling water depletion in the root zone under the application of different amounts of irrigation water. Models that simulate crop growth and water flow in the root zone can be powerful tools for extrapolating findings and conclusions from field studies to conditions that have not been tested.

In this context, the objective of this part of the study is outlined in the following:

- To validate the Yield-Stress model for wheat yield data at two sites in Egypt
- To predict the changes in yield of wheat and other primary crops (cotton, soybean, clover, faba bean, and onion) under deficit irrigation practices where the crops are irrigated with smaller amounts of water than their full irrigation requirements
- To decide on the most appropriate irrigation regimes to be implemented for the various crops, which save water and, at the same time, maintain satisfactory crop production without any notable yield losses
- To test the capability of the Yield-Stress model in irrigation scheduling.

The findings of this research can be summarized as follows:

- Based on the comparative analysis between the measured and predicted yield data of the crops investigated under varying degrees of water stress, we conclude that the Yield-Stress model can adequately predict yield reductions. The model can provide useful insights into the design of different irrigation treatments. The ease of implementation of the model can help in the wider use of the deficit irrigation technique and help achieve a saving of water in the agriculture sector. The results of the model validation under full irrigation volumes and under deficit irrigation treatments give a clear cut answer confirming the model's appropriateness in predicting yields and investigating the degree of tolerance of crops to water-stress. Furthermore, the results also suggest that the model can be used in irrigation scheduling to conserve irrigation water with almost no reduction in yield.

- For all the crops investigated, the deficit irrigation technique was practiced successfully. This leads to the conclusion that the crops under investigation can be grown successfully without any appreciable losses in yield using less water than is currently the case. However, the point that needs to be clarified is the extent to which the water supplied can be reduced without resulting in harmful effects on the crop yield.
- The crops under investigations vary greatly in their degree of tolerance to water- stress.
- Cotton was the crop among those studied which can be produced successfully using 30% less water than that corresponding to full irrigation.
- Wheat can be produced successfully using up to 20% less water without any deterioration in the yield. This was also the case for onion. Both wheat and onion could be considered as crops moderately tolerant to water-stress.
- The situation with the other crops investigated was to the contrary. Faba bean is shown to be an intermediate crop where up to 15% of the total amount of water applied could be saved without any significant losses in the yield. Soybean and clover are the poorest among the crops studied in tolerating stress conditions. Both can be safely grown under irrigation with just 10% less water than that required for full irrigation.
- The crops investigated can be classified according to their tolerance to water stress, using the yield under varying degrees of water stress as an indicator, as indicated in Table 4.42.

Table 4.42. Classification of investigated crops according to their degree of tolerance to water-stress.

Crop	Water stress degree	Water saving(%)
Cotton	Highly tolerant	30%
Wheat Onion	Tolerant	20%
Faba bean	Intermediate semi-tolerant	15%
Clover Soybean	Sensitive less tolerant	10%

In spite of the variations in the resistance to water-stress conditions of the crops investigated, generally all of them can be produced successfully and safely with less volumes of water than those that are traditionally used for irrigation. In other words, it can be concluded that there is a high potential for water saving in the irrigation sector by increasing crop water productivity and producing more with less water.

One of the promising options for meeting the gradually increasing water demand, given the limited and fragile nature of the water supply, is to introduce water of known quality and drainage water as supplementary irrigation water sources. Nowadays, it is the policy of the government to fully use drainage water in irrigation to increase, on the one hand, the water allocated to agriculture and, on the other, to save a relatively high volume of freshwater to compensate for increasing water shortages in the other sectors that use water.

The challenge for the future will be to maintain, or even increase, water productivity using less water or by using water of low quality.

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Chapter 5: Socioeconomic assessment of improved water management practices in Egypt’s irrigated agriculture

Chapter 5: Socioeconomic assessment of improved water management practices in Egypt's irrigated agriculture

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5.1 Introduction and justification

Egypt has a cultivated area of 3.3 million ha, of which 2.6 million ha is the old lands of the Nile Valley and Delta, and the rest (0.7 million ha) is new land (including the salt-affected area in the north of Delta). The cropped area is 5.8 million ha with a cropping intensity of 1.8.

Egypt has limited its share of the Nile River to 55.5 billion m^3. Meanwhile, water demand is continuously increasing due to population growth, industrial development, and increasing living standards. With limited renewable fresh water resources and a continuous increase in water demand, the issue of future water planning for Egypt becomes very serious. If the present management practices and cropping patterns prevail, this could mean that up to 60% of the agricultural land will not be irrigated, (Resource Management (RM), Nile Valley and Red Sea Project (NVRSP).

A review and analysis of a relevant set of previous projects' activities (e.g., RM., Long-term Trial (LTT)/Long-term Monitoring (LTM), NVRSP, Agricultural Policy Reform Project (APRP-RDI)) provided a base line for this project and revealed that there are three major eco-systems in Egypt:

1. Old lands that include all cultivated areas in the Delta
2. Newly reclaimed lands that include El-Bustan area (sandy calcareous land)
3. Salt-affected lands that are threatened by sea-water intrusion and a shallow water-table.

The objectives of this report are to evaluate and test, with community participation; the benchmark water management options which sustainably improve water productivity, net return per water unit, and optimize water use. The strategies evaluated have to be economically viable, socially acceptable, and environmentally sound in the three different agricultural eco-systems. These eco-systems are located on three selected canals, the Alatf canal (improved versus not-improved misqa community in the Menofia Governorate), the El-Bustan canal (a water users association (WUA) versus a no water users association community in the Nubaria Area), and El-Shoka canal (a fresh water using versus a drain water using community in Damietta Governorate).

This report assesses and evaluates the Egyptian Irrigated Benchmarks site. Given the limitations of the data obtained from the trials conducted, the results presented are preliminary and subject to further verification through wide-scale experimentation and in demonstration trials on farmers' fields.

5.2 Site Selection and portability study

5.2.1 Site and community selection (Figure 3.1)

Three representative sites (old lands in the middle of Delta, new lands in Nubaria, and salt affected lands in north Delta) have been purposely selected across three chosen canals – the Alatf (in Menofia Governorate), El-Bustan (in Nubaria Area) and El-Shoka (in Damietta Governorate). With the participation of local agricultural cooperative members and leaders, who are involved in the planning and implementation of research, each selected site was classified into 2 or 3 communities based on water use, water quality, or the existence of a Water Users Association (WUA).

5.2.2 Preparatory studies

Three types of preparatory studies have been carried out since January 2005 to collect data that would help the multi-disciplinary team (MDT) to define the site characterization and sample design.

5.2.3 Review studies

Participatory Rural Appraisal (PRA)

Based on the information gap identified through the review of secondary information, additional data was collected using the participatory diagnosis (PD) methodology to get a deep understanding of the targeted communities. The volume and type of data collected depended on the information gaps and the degrees of precision and depth of analysis required for the diagnosis. A community based approach, ensuring community participation was adopted. A participatory rural appraisal (PRA) and its associated tools were applied to collect information to facilitate characterization of the selected sites.

Multidisciplinary surveys (MDS)

Multidisciplinary surveys were carried out to assess general feelings and values and to identify issues for in-depth investigation. Accordingly, after completing MDS for the selected sites, the MDS team randomly selected between 10 and 15 farmers from each selected community and interviewed them. The MDS questionnaire sought information on the following topics: farm system, farm income, crop rotation and pattern, water and soil management, productivity, farmers' preferences for different practices, farmers' awareness (knowledge), and the impact of new technology.

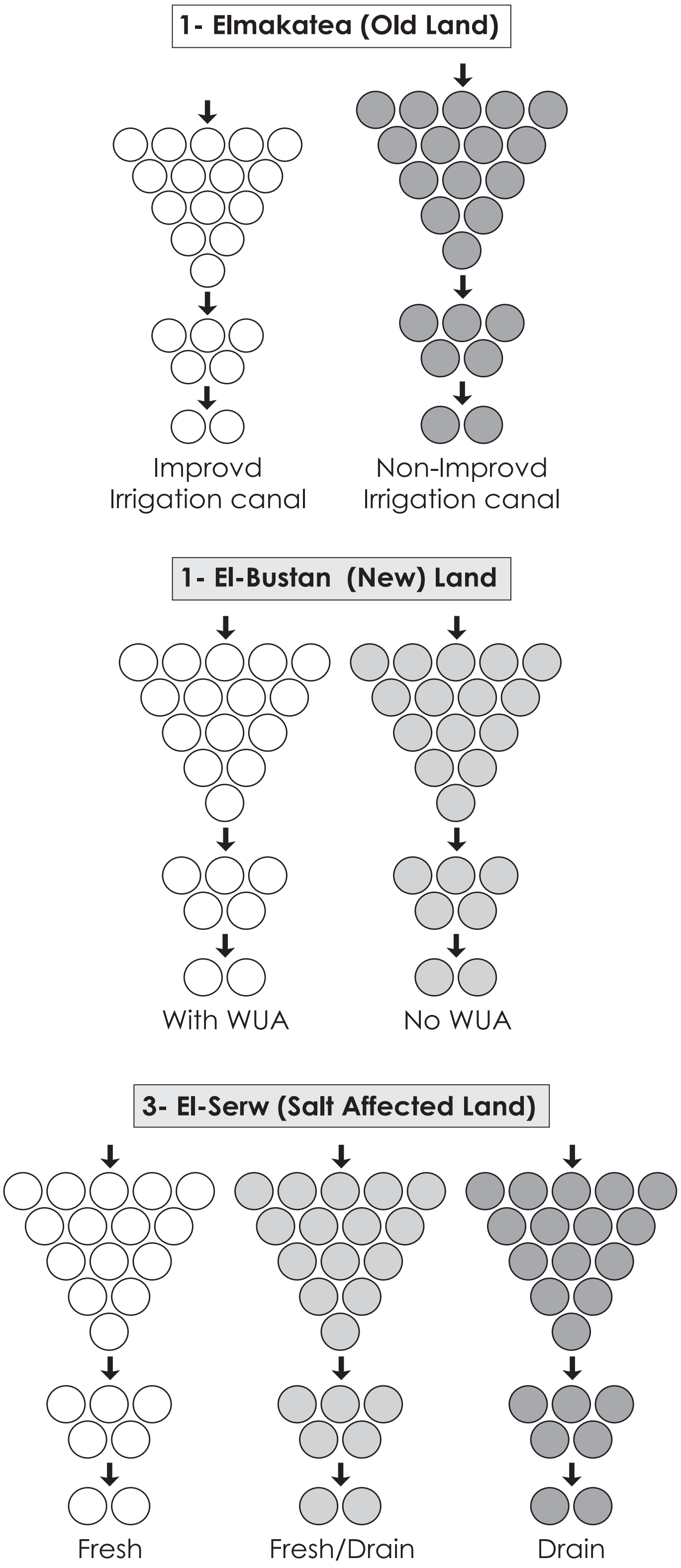
Monitoring and evaluation (M&E) surveys

A sample, of size five, farms/farmers was selected from each community to monitor the change in the farms' resources over time as a result of the farmers' practices. Finally, two of the farms/farmers being monitored were selected for water trials, sound agronomic practices, and farmers' perception. The socioeconomic team carried out two monitoring and evaluation (M&E) surveys annually, one in November to monitor the farming practices of the summer season and the other in June to cover the winter season. The team interviewed 10 farmers from the old lands, 10 from the new lands, and 15 from the salt-affected lands, using the participatory approach. The M&E questionnaires were completed and the data were processed into the database.

With the information from previous studies, PRA and MDS farmers/farms were selected for M&E and modeling activities from each site. Two-stage cluster sampling was used to select five farms from each community in the first stage for M&E activities. In the second stage, two farms were selected from these five for field trials and modeling. In a few instances some of the farmers selected for the trials in the first year were replaced in the second year with new ones. The clusters in each site are shown in Figure 5.1. These clusters are as follows.

Old lands

El-Makataa was the site selected in the old lands. The selected area was divided into two communities based on the construction of the irrigation system. The first one was an improved system misqa community and the other was as unimproved misqa community. The water flow is continuous in the improved system, while in the unimproved system it is based on a seven day irrigation cycle.



1 – Two communities across a misqa

15 farms: MDS, Sept/Oct 2005

5 farms: M&E 2005, 2006, 2007

2 farms: field interventions (modeling and field trials)

2 – Two communities across WUAs

15 farms: MDS, Sept/Oct 2005

5 farms: M&E 2005, 2006, 2007

2 farms: field interventions (modeling and field trials)

3 – Three communities across sources of water

10 farms: MDS, Sept/Oct 2005

5 farms: M&E 2005, 2006, 2007

2 farms: Field interventions (modeling and field trials)

Figure 5.1. Site and community selection

New lands

The village of El-Hussein in El-Bustan was selected as the representative site of the new lands. Two communities were selected in El-Hussein area, one which had established a water users association (WUA) and the other without one (No WUA).

The marginal lands

These are salt-affected soils located in the north of the Delta. This area is threatened by sea water intrusion and a shallow water table. El-Serw was selected as the representative site for this type of land. Three communities were selected based on their source of water and the water quality; El-Talamza as the representative community for a fresh water source, El-Sebakhat as the representative community for fresh and drain water sources, and Khareg El-Zimam as the representative community for a drain water source.

5.3 Simple methodology for economic evaluation of the tested options

Enterprise budgets analysis is used to compare the profitability of the alternative options. These budgets help ensure that all costs and receipts for crop budgets under the irrigation benchmark (IB) options are included. Often receipts and costs are difficult to estimate in budget preparation because they are numerous and variable. Net returns are calculated as the difference between total revenue (price * yield) per hectare and total variable costs which include land preparation, weeding, irrigation, and harvesting, and input costs, such as seed, fertilizer, manure, and chemicals. Fixed costs, such as land rent, were excluded as these are irrelevant to the farmers' decisions regarding their technology choices since crop yields are independent of these costs.

Because of the emphasis of the benchmarks project, returns to water application, (measured in EGP/m^3) are used as a measure of water productivity. This is obtained by dividing net returns per hectare by the amount of water applied per hectare. The results of both net returns and water productivity are presented as the average value for the two seasons for each crop. The results for each site are also disaggregated for the communities involved.

5.4 Results and discussion

5.4.1 Old land site

On the old lands, the major constraints to sustainability include poor water management and land fragmentation. The options tested include crop-specific irrigation regimes (full, deficit and raised bed options), full irrigation, and traditional farmers' practice on winter wheat and maize crops on the improved and unimproved misqa. Full irrigation is meant to meet the full crop water use and leaching requirement, while deficit irrigation represents 70% of the amount of water for full irrigation.

The results of the enterprise budget analysis for 2005-2006 and 2006-2007 (data not shown) indicate the superiority of wide furrow compared to the farmers' irrigation practice for wheat. The productivity and total returns increased by between 5% and 6%. Total variable costs decreased by between 7% and 8%, and returns over variable costs increased by between 12.5% and 13%. Net returns increased by between 5% and 10%. Accordingly, the new irrigation option, the raised bed (wide furrow) system, is expected to save between 20% and 30% of the irrigation water and be more profitable, accepted, and adopted by farmers either for winter or summer crops in the old lands.

Table 5.1 compares the profitability per unit area and water productivity (WP), in terms of the return per unit of water, in the old lands. Wheat farmers who applied wide furrow and deficit (70% of full) irrigation options had, on average, the highest returns per unit of water – wide furrow irrigation, EGP 3.24/m^3 and deficit irrigation, EGP 3.31/m^3. Wide furrow irrigation had the highest profit value (EGP 12,296/ha) compared to that from the farmers' practice (EGP 11,630/ha), full water requirement (EGP 11,557/ha) and 70% of the full requirement (EGP 11,976/ha). Wheat profitability under the alternative options is almost the same. However, the deficit irrigation and wide furrow options yielded much higher water productivity (returns per unit of water). Thus, the full requirement used in this experiment may have been overestimated. Future trials need to estimate this value more accurately.

Maize growers had a slightly higher returns to water application, EGP 0.77/m^3 (for the wide furrow option) and EGP 0.73/m^3 (for the deficit irrigation option), as compared to that for the farmers' usual practice and the full irrigation requirement options. However, these differences between the different options for maize are very small. In terms of net returns, the farmers' usual practice and full requirement have almost the same level of returns, while returns under deficit irrigation and wide furrow are slightly higher.

Wheat farmers following the raised bed (wide furrow) and deficit (70% of requirement) options obtained higher water productivity that amounted to 2.83 EGP/m^3 and 2.97 EGP/m^3, as compared to farmers' practice and the full requirement options in all systems (Figure 5.2). However, there was a higher potential for improving water productivity on unimproved misqa than on farms on improved misqa. This reflects the possibility of higher water losses and the tendency of farmers to over-irrigate their wheat crops in the unimproved systems. This may also be because the farmers using the improved misqa have continuous water access while those on the unimproved misqa do not.

Maize farmers using the raised bed (wide furrow) and deficit (70% of full) options obtained higher water productivity – 0.74 EGP/m^3 for the former and 0.70 EGP/m^3, for the latter – during the 2006-2007 season as compared to farmers' practice (0.65 EGP/m^3) and full requirement irrigation options (0.65 EGP/m^3), as shown in Figure 5.3. Unlike the wheat farmers, the maize farmers at the improved misqa community were less efficient in managing water resources under all the options tested except the farmers' option. In contrast to wheat,

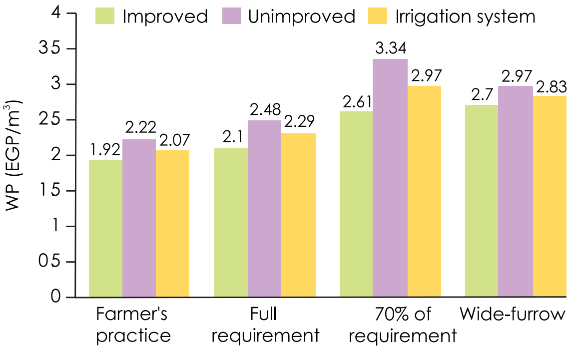


Figure 5.2. Average WP (EGP/m^3) for wheat crop grown under different IB options over the two seasons 2005-2006 and 2006-2007.

Table 5.1. Average net returns and WP of wheat and maize in the old lands (2005-2007).

Options	Wheat (2005-2006 and 2006-2007)		Maize (2006-2007)	
	Net returns (EGP/ha)	**Water productivity (EGP/m^3)**	**Net returns (EGP/ha)**	**Water productivity (EGP/m^3)**
Farmer	11,730	2.28	4,419	0.72
Full requirement	11,557	2.56	3,938	0.68
70% of full req.	11,976	3.31	4,745	0.73
Wide furrow	12,296	3.24	4,285	0.77

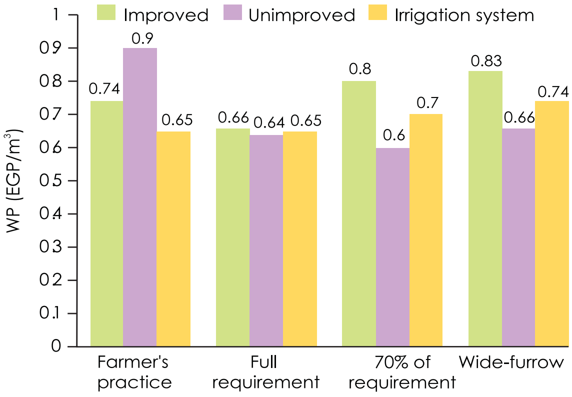


Figure 5.3. Average WP (EGP/m^3) for maize crop grown under different IB options, over the seasons 2005-2006 and 2006-2007.

the WP of maize is much lower given the relatively higher prices and yield of wheat as compared to maize.

5.4.2 New land sites

On the new lands, the sandy soil and over and/or inadequate irrigation represent the major constraints to the sustainability of improving water productivity in this system. The options tested included full crop requirement, deficit irrigation management representing 80% of the full crop requirements, and the farmers' usual practices. These options are applied to sample farms from both the WUA and No WUA groups for wheat and groundnuts, the two major winter and summer crops grown on this system.

Using enterprise budget analysis, the total returns, costs, and net return are estimated under the alternative irrigation systems. The results of the enterprise budget analysis for wheat for the 2005-2006 and 2006-2007 seasons and groundnut for the 2006 and 2007 seasons suggests that the total return was increased by between 3% and 7%. Deficit irrigation also reduced costs by between 5% and 7%, energy by between 17% and 30%, labor by 20%, and increased water saving by 25% as compared to the farmers' irrigation practice. Accordingly, using deficit irrigation in the new lands is a promising option.

The net returns and WP of wheat and groundnut grown on the new lands using the farmers' practice, full irrigation requirement, and deficit irrigation at 80% of the full requirement are compared in Table 5.2. The wheat yields are much lower on the new lands as compared to those on the old lands because of the known differences in soil quality. Consequently, both net returns and water productivity in the new lands are much lower.

Wheat returns per unit area on the new lands showed only limited variability under the different options, with highest returns being obtained with the deficit option (EGP 4874/ha). Also, this option resulted in the highest water productivity (EGP 1.59/m-3). This arose because of the relatively small reduction in yield (5%) as compared with that obtained under the full requirement and the yield being almost the same as that obtained using the farmers' practice.

Table 5.2. Average net returns and WP for wheat and groundnut in the new lands in the period 2005 to 2007.

IB options	Wheat (2005-2006 and 2006-2007)		Groundnut (2006 and 2007)	
	Net returns (EGP/ha)	Water productivity (EGP/m^3)	Net returns (EGP/ha)	Water productivity (EGP/m^3)
Farmer	4,591	1.10	5,642	1.03
Full requirement	4,586	1.15	6,063	1.09
Deficit (80% of full)	4,874	1.59	5,596	1.18

This appears to be a promising option for improving WP without affecting profitability and wheat yields.

The returns and WP for groundnut in the new lands have shown limited responses to the alternative irrigation options. The net returns from groundnuts ranged from EGP 5596/ha to EGP 6063/ha, while water productivity increased from EGP 1.03/m^3 with the farmers' practice to EGP 1.09/m^3 under full irrigation, and EGP 1.18/m^3 under deficit irrigation, as shown in Table 5.2. The deficit irrigation option appears to be a promising one for groundnuts on the sandy soils of the new lands.

Wheat growers in the 2005-2006 and 2006-20078 seasons who followed the deficit irrigation option had, on average, the highest net return per unit of water used (EGP 1.57/m^3) as compared to the other options – farmers' practice, EGP/ m^3 1.1, and full irrigation requirement EGP 1.15/m^3 (Figure 5.4). The management of irrigation water resources practices of those farmers who are members of the WUA are, apparently, less efficient than those of the farmers who are not members. This is a surprising result, particularly when compared to the relatively high productivity of the members using the full requirement and deficit irrigation options. This may suggest that combining the water saving techniques (the technology options) with institutional reforms may increase the efficiency of water use.

The aggregated results of the two summer seasons for groundnut do not show a clear advantage for any of the options and between the two institutional settings (Figure 5.5). The difference in water productivity is very small, although deficit irrigation does show a slight advantage compared to the farmer's practice and full irrigation options. These results are inconclusive and should be interpreted with caution given the limited sample size in these trials.

5.4.3 Salt-affected land sites

Poor water management and water quality represent the major constraints to productivity for this system. Under this system, the options tested with wheat included crop-specific irrigation regimes (full, deficit and raised bed options) and compared these to farmers' traditional practice. These options were tested under three sources of irrigation water – fresh water, fresh and drainage water mixed, and drainage water only.

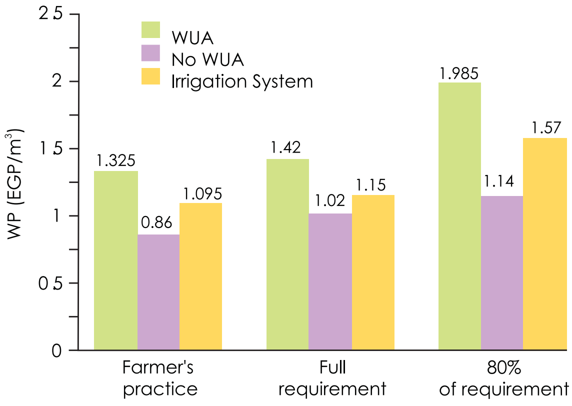


Figure 5.4. Average WP (EGP/m^3) for wheat crop under different irrigation options over two seasons (2005-2006 and 2006-2007) in the new lands.

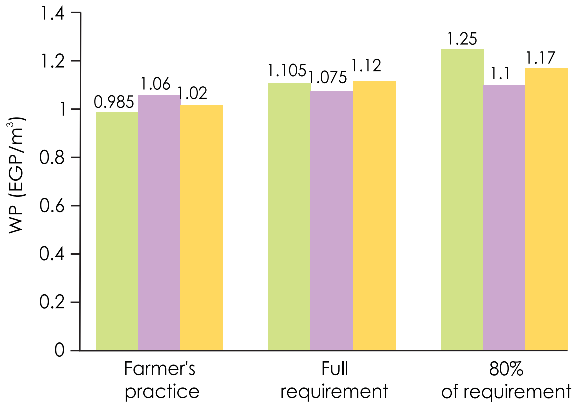


Figure 5.5. Average WP (EGP/m^3) for groundnut grown under different irrigation options in the 2006 and 2007 seasons in the new lands.

Using enterprise budget analysis, the total returns, costs and net return were estimated for alternative irrigation systems, including full irrigation, deficit irrigation (80% of the full requirement), and farmers' practices. The changes in net benefit over time were monitored. The results of the enterprise budget analysis for wheat, for the 2005-2006 and 2006-2007 seasons, and rice, for the summer seasons of 2006 and 2007, revealed that total returns and total productivity were decreased by between 6% and 10%, but wheat productivity was increased by 6%. Under deficit irrigation, total productivity and total returns were decreased by between 15% and 18%. Compared with the results from the farmers' irrigation practice, deficit irrigation reduced costs by between 8% and 16%, energy by between 5% and 24%, labor by between 20% and 30%, and increased water saving by between 20% and 25% percent. Accordingly, applying deficit irrigation in the marginal lands is questionable and needs further demonstrations and experimental work to prove any potential. This is especially so in the salt-affected soils in the northern Delta at El-Serw where the experimental work was carried out.

For rice, the alternative irrigation options to the farmers' traditional practices on marginal land involved reducing irrigation frequency to four and eight days or reducing the amount applied to the field capacity level. Of these, the saturation option involves applying the smallest amount of water. Under these options, the profitability of rice increases from EGP 4369/ha for saturation to EGP 5773/ha for the farmers' practice (see Table 5.3). The reduction in frequency of rice irrigation to every eight days increased the water productivity by 20% compared to farmer's practice.

For rice, the farmers' practice was compared to three levels of irrigation frequency, every four days, every four to eight days, and at saturation. In the marginal lands in the summer seasons of 2006 and 2007, irrigation every four days had, on average, a net return for WP for farmers who applied the saturation option of EGP 0.52/m^3 while that for farmers who irrigated every four days was EGP 0.51/m^3. Both of these were higher than the net return for WP for the other irrigation system options (Figure 5.6). However, rice has a much lower productivity than wheat in this system. For returns based on the quality of the water used, farmers using drainage water obtained the highest water productivity.

The wheat experiment involved two alternative options to the farmers' practice – full requirement and deficit irrigation (70% of full requirement). For wheat grown on this marginal land, the levels of return are very similar with the highest returns occurring for the full irrigation requirement option. However, the deficit irrigation option showed substantial gains in WP (35%) and thus appears to be a promising option for wheat. So, deficit irrigation appears to be a promising option for improving water productivity in wheat production under the conditions of the three ecosystems. For the

Table 5.3. Average net returns and WP for wheat and rice in the marginal lands for the growing seasons between 2005 and 2007.

Wheat (2005-2006 and 2006-2007)			Rice (2006-2007)		
Irrigation treatment	**Net returns (EGP/ha)**	**Water (EGP/m^3)**	**Irrigation treatment**	**Net returns (EGP/ha)**	**Water productivity (EGP/m^3)**
Farmer	5,194	1.00	Farmer	5,773	0.45
Full requirement	5,676	1.14	Every 4 days	5,710	0.51
70% deficit	5,021	1.35	Every 8 days	5,513	0.56
			Saturation	4,369	0.52

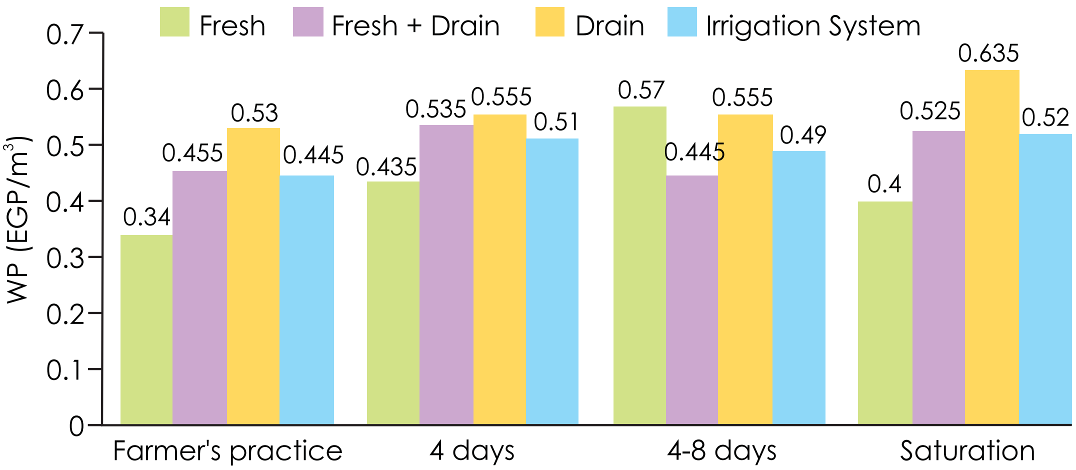


Figure 5.6. Average WP for rice grown under different irrigation options for the summer seasons of 2006 and 2007 in the marginal land.

summer crop, deficit irrigation is a promising option only for groundnut on the new lands. Given the existing data, more investigation is needed to identify the most promising option for the summer crops in the old and marginal lands.

Wide furrow and deficit irrigation (70% of the full requirement) options, at all the communities had, on average, higher net returns per unit of water. These amounted to EGP 1.57/m^3 for wide furrow and EGP 1.32/m^3 for deficit irrigation. These compare favorably with EGP 1.04/m^3 under the farmers' practice and EGP 1.15/m^3 for the full requirement option (see Figure 5.7). Wide furrow irrigation had in fact the highest value for WP for comparable treatments. for all qualities of water. Also, the drain water system has the highest WP under all options.

A study was designed to investigate the influence of the new irrigation options (wide

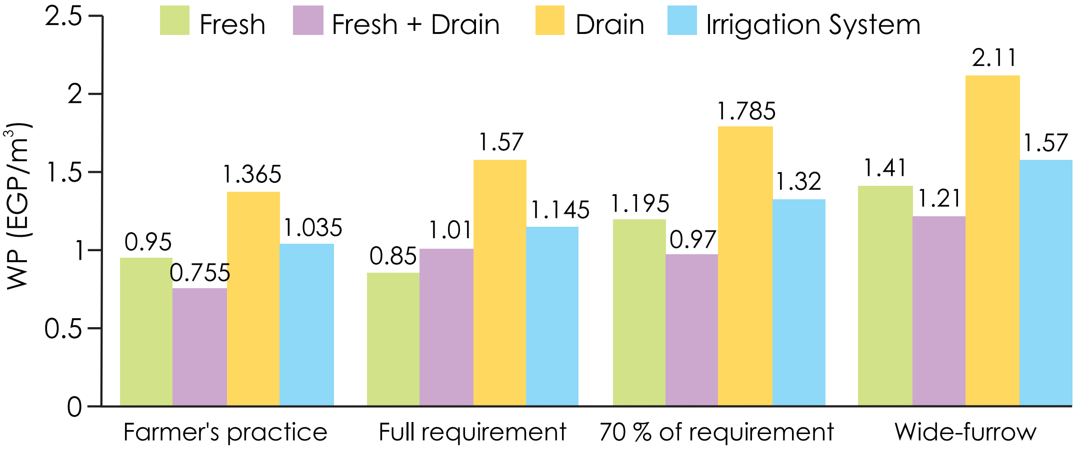


Figure 5.7. Average net WP (EGP/m^3) for wheat grown under different irrigation options for two seasons 2005-2006 and 2006-2007 in the marginal lands.

furrow) on yields, costs, and gross benefits. This study was applied to demonstration fields of faba beans grown during the winter of 2006-2007 across neighboring governorates - Bohaira, Fayoum, and Minia. Several economic yield indicators including total return (gross return), net benefit, costs, cost that vary due to the intervention, and the B/C ratio were explored in Tables 5.4, 5.5, and 5.6 as follows;

5.5 Conclusions and lessons learned

Enterprise analysis, partial budget, and economic analysis indicated the superiority of the new irrigation benchmark options for increasing net returns per unit of water, reducing costs, and saving water as well as offering the potential to increase farm income, livelihood, and alleviating poverty.

Table 5.5. Partial budget for different irrigation options for faba bean in different areas during the 2006-2007 season in Fayoum Governorate.

Fayoum district	Irrigation options	Yield (t/ha)	Total Return (EGP/ha)	Total variable costs (EGP/ha)	Net return (EGP/ha)	Intervention costs that vary (EGP/ha)	Benefit/ cost ratio
Abshway	Wide furrow	1.9	13,137.6	2,668.0	10,469.6	95.2	4.9
	Traditional furrow	1.6	10,852.8	2,715.6	8,137.2	142.8	4.0
	Difference	0.3	2,284.8	-47.6	2,332.4	-47.6	
	Difference (%)	18.7	21.1	-1.8	28.7	-33.3	
Fayoum	Wide furrow	1.9	5520.0	1,115.5	4,404.5	62.5	4.9
	Traditional furrow	1.7	5040.0	1,123.0	3,917.0	70.0	4.5
	Difference	0.2	480.0	-7.5	487.5	-7.5	
	Difference (%)	11.8	9.5	0.7	12.5	10.7	

Table 5.6. Partial budget for different irrigation options for faba bean in different areas in the 2006-2007 season in Menia Governorate.

Fayoum districts	Irrigation options	Yield (t/ha)	Total return (EGP/ha)	Total variable costs (EGP/ha)	Net return (EGP/ha)	Intervention costs that vary (EGP/ha)	Benefit/ Cost ratio
Banymazar-A	Wide furrow	1.9	14280.0	3189.2	11090.8	238.0	4.5
	Trad furrow	1.4	10710.0	3308.2	7401.8	357.0	3.2
	Difference	0.5	3570.0	-119.0	3689.0	-119.0	
	Difference %	33.3	33.3	-3.6	49.8	-33.3	
Banymazar-B	Wide furrow	1.9	13994.4	3324.9	10669.5	238.0	4.2
	Trad furrow	1.2	9329.6	3443.9	5885.7	357.0	2.7
	Difference	0.6	4664.8	-119.0	4783.8	-119.0	
	Difference %	50.0	50.0	-3.5	81.3	-33.3	

Table 5.4. Partial budget for different irrigation options for faba bean in areas during the 2006-2007 season in Bohaira Governorate.

Bohaira district	Irrigation options	Yield (t/ha)	Total return (EGP/ha)	Total variable costs (EGP/ha)	Net return (EGP/ha)	Intervention costs that vary (EGP/ha)	Benefit/cost ratio
Shobrakheit	Wide furrow	1.9	11,650.1	3,205.9	8,444.2	100.0	3.5
	Traditional furrow	1.6	10,210.2	3,255.8	6,954.4	149.9	3.0
	Difference	0.3	1,439.9	-49.9	1,489.8	-49.9	
	Difference (%)	18.7	14.1	-1.5	21.4	-33.3	
Abouhmos	Wide furrow	1.9	10,567.2	3,420.1	7,147.1	100.0	3.0
	Traditional furrow	1.2	6,640.2	3,520.0	3,120.1	199.9	1.8
	Difference	0.7	3,927.0	-98.9	4,026.9	-99.9	
	Difference (%)	58.3	59.1	-2.8	129.1	-50.0	

Specifically, the wide-bed furrow option was best suited for wheat and faba bean in the winter season and for maize in the summer season. It was also found that the saturation option had a potential for rice in the marginal land of El-Serw. The deficit irrigation option was found to be the second choice for winter crops, especially wheat. However, productivity might decrease under the saturation and deficit options.

- Results of the experimental field trials and the M&E information analysis revealed that wide furrow irrigation has a higher potential to enhance the net return on a unit of water for wheat and faba bean in all ecosystems and for maize crops in the old lands as compared to other irrigation options.
- Partial budget analysis of scaling-out in the governorates showed that wide furrow always has a higher benefit to cost ratio (B/C ratio), The average increase in the net benefits and B/C ratio of the new option, wide furrow, were, on average, 40% and 20% in all the governorates studied. Meanwhile, the wide furrow option reduced variable costs by 30% on average. Scaling-out analysis showed that wide furrow was a more profitable option, widely accepted and adopted by communities in the project areas and the neighboring governorates.

On marginal lands, farmers usually irrigate their wheat every seven days and keep the water level at 15cm on rice. However, the quantities of water applied vary from season to season and between farmers even for the same treatment. This makes the results of the experiment extremely difficult to interpret. Moreover, experiments were not conducted with the same set of farmers in the two seasons and input use and management levels vary significantly between farmers. For example, some farmers manure their plots, while others do not and the quantity of nitrogen applied varied between farmers and between years. This is very critical in these trials since water productivity is influenced significantly by the productivity of other inputs. Given the small sample (2 to 3 farmers), further analysis of the data to account for all these factors is not possible. Therefore, these results should be taken with caution and final recommendations should be subject to further experimentation and monitoring with a proper experimental design, suitable sample size, and accurate monitoring and measurement of other management practices and input use.

Chapter 6: Role of current policies and institutions Egypt in improving irrigated agriculture

Chapter 6: The role of current policies and institutional setups in Egypt in achieving improved and sustainable irrigated agriculture

D. E. El Qausy, K. Shideed, T. Oweis, and M. Karrou

6.1 Evolution and history of water policies in Egypt

The objective of any national water policy is, normally, to 'Generate the maximum possible economic value for the nation'. Under water scarcity situations, water should be allocated so that users who generate a higher income per unit volume of water are given priority over those who generate less income. This applies not only to water quantity, but also to water quality. The above statements are valid when water is considered as an economic commodity.

If other dimensions, such as social, political, and security ones, are added, the objective of the national water policy remains unchanged, while water allocation and use between different activities will have a different meaning. Although water is almost universally regarded as a public property, economic instruments provide ways and means through which to achieve maximum welfare in the sense that each user must compare the value of water he is using with the 'opportunity cost' of other or alternative users.

Unfortunately, this understanding is not common in most of the developing countries because of the following factors:

- Cultural and historical beliefs that water is free for all citizens
- Land fragmentation which causes extremely low water productivity
- Lack of water measuring devices and tools
- Poverty and low standards of living among farming communities
- Increased taxation for other reasons
- Aging irrigation systems of a primitive nature
- Large percentage of man power involved in farming activities
- Low prices for agricultural products at the farm gate
- Centralization of irrigation and agriculture at all levels
- Poor participation of farmers in system management
- Outdated institutions and slow renovation
- Domination of supply management at the expense of demand management and market-driven mechanisms.

'Economically efficient allocations' are defined as allocations that maximize the value derived from water use. These can only be achieved if a user's demand for water and willingness to pay compare to the willingness of other users to pay the cost of supply. That is, full economic allocation is achieved by open markets where individuals, groups, and companies of a private or public nature can trade water according to cost and benefit. This requires two institutional arrangements.

- Water allocations must be clear and secure
- Transfer of allocations must be feasible and of low cost.

However, allocations may prove to be inefficient for one or more of the following reasons:

- Natural monopolies caused by the market mechanism and directing allocations to activities which are not necessarily in accordance with the priorities of society

- Free of charge water, or tariffs lower than market value encouraging misuse by the users and result in the total benefit to society being less than it could be if the water was allocated according to its real value
- Revenues are often less than the cost of operation and maintenance which results in a budget deficit and deterioration of the water facilities
- Failure to determine the levels of pollution that are associated with optimal production or, in other words, failure of regulatory bodies to force the polluter to pay (the polluter pays principle) and to be accountable for the damage they cause.

The above economic considerations are substantially needed to frame water policies. However, when the water supply was in excess of population needs, a relaxation of governing rules used to prevail. Most of the countries around the world and, in particular, the countries of the WANA region (Egypt is one of these) have experienced sharp increases in their populations, increased standards of living and fixed or even reduced availability of water. As a consequence they felt it necessary to review their strategies, policies, and programs in order to cope with the existing conditions as well as to prepare themselves differently for the future by adopting policies which lead to higher 'water productivity' and higher 'water use efficiency.

6.2 Review of previous water policies in Egypt

A policy is defined as a course or principle of action designed to achieve particular goals or targets. Historically, water policies in Egypt started with the dawn of civilization. The Egyptian Pharaohs surprised the world with their ability to manage the Nile water, maximize food production, and use the local population to generate the revenues needed to run the first well organized state in the history of mankind. In recent history, it was Napoleon Bonaparte who stressed the need for storage in the Egyptian system. He is quoted as saying; "Si je devrais gouverner ce pays, pas une goutte d'eau ne se perdait dans la mer." (If I am to rule this country, I will not permit a drop of water to flow to the sea.).

The Egyptian ruler Mohamed Ali (1805-1845) extended water management to the remodeling (widening and deepening) of the Nile branches in the Delta (there were six branches). He also constructed two major head regulators on the two main branches at Rosetta and Damietta. In this age, agricultural development flourished, the area of cultivated land doubled, cropping intensity increased from less than 100% (one crop per year) to more than 150%, through the introduction of summer (cotton and maize) and perennial crops (sugarcane and fruit trees).

Water policies based upon sound scientific principles started as early as the 1920s and continued throughout the century until the last policy was introduced in 1997 to cover four plans each lasting five years, i.e., ending by 2017. The summary of these policies can be briefly spelled out as follows:

- Following the construction of the Delta barrages (1830-1840), a number of superstructures were raised starting with Aswan Dam (1898-1902). These were followed by the Isna, Nag-Hammadi, and Assiout barrages on the main Nile, and the Zefta and Edfina barrages on the Damietta and Rosetta branches. The construction of the high Aswan Dam in the mid 1960s heralded the era of full management of water in Egypt.
- Throughout history, Egypt has enjoyed a surplus in the amount of water required to meet regular demand, except of some cycles of drought, the last of which badly hit the African continent and lasted for about ten years (1977-1987).
- Known as an agricultural country, agricultural activities expanded

horizontally and vertically in order to meet the expanding demand for food and natural fiber both in the local market and for export. This expansion enlarged the workforce in agriculture until it included almost 40% of the manpower in the country.

Industry started on agri-products such as sugar, textiles, oil, leather, paper, fertilizers, wood, etc.

The first water policy cited in the last century was the 1928 policy, which fixed the limit of horizontal expansion at 7.17 million feddan. This figure was realized by the end of the century, seventy years after the policy was issued.

The fast growing population, forced successive governments to direct the economy towards industrial development in order to meet the needs of the increased population and raise their standards of living. Heavy industry was then started, followed by tourism and services as high priorities.

At present, the amount of potable water produced is about 24 million m^3/day, or about 9 billion m^3/year. If the existing trend in population growth and consumption continues, by 2020 the number of Egyptians is expected to reach 100 million. By that time, the demand for potable water would be around 11 billion m^3/year, about 20% of the Egyptian quota of the Nile waters.

In the meantime, other activities, such as industry and tourism, are flourishing. Egypt is expected to be the world's cement factory (production has risen from 9 million t/year to 24 million t/year in just a few years). Other industries, such as fertilizers, steel, aluminum, chemicals, pharmaceutics, and many others, are providing significant temptations to regional and international investors. The real estate industry is moving fairly fast to occupy the empty quarters in the existing cities, to fill the space in the wide deserts, and to urbanize huge areas in the Nile valley and Delta. This pressure for development arises mainly because of population pressures and the need for summer and winter resorts and recreation areas. Tourism, which provides the country with good part of its hard currency revenues – 11 million tourists per year, spending more than 100 million nights – is expected to exceed 14 million guests in the near future.

Obviously tourism is not limited to hotel hospitality, but extends to golf courses, swimming pools, lakes specially established for immigrant birds, and luxurious fountains in addition to the high consumption of tourists in a temperate country. All these increases in water consumption are expected to subtract from the quota for agriculture for two simple reasons:

- The economic return of a unit volume of water in agricultural production is lower than that of other activities.
- A high proportion of the losses in agriculture are irrecoverable unlike other activities where the majority of losses can be recovered, treated and recycled.

This state of affairs can only be overcome if new water resources are developed, mainly via cooperation with Nile Basin countries. This is not expected to be achieved, at least in the near future. The second and more realistic option is for agriculture to modernize its on-farm irrigation system and change cropping patterns. Both actions should be developed to use less water for the production of high return commodities.

6.3 Interpretation of successive water policies

A detailed review of water policies in Egypt covering the period 1928 to 2017 is given in the report entitled Policies and Institutional Setups, October 2006. Interpretation of these policies is given below:

Successive water policies in Egypt marked historical events in the country's development plans:

The 1928 policy came just one year before the introduction of the 1929 agreement in which Britain, as an occupying country of Kenya, Uganda and Tanganyika, (Tanzania after being unified with Zanzibar), and Sudan; agreed with Egypt to stop abstraction of Nile water during the period of peak demand (May to July) for the purpose of securing enough water for the irrigation of cotton fields in the Nile Delta in Egypt. This rule was even extended to Upper Egypt where Nile water was restricted during this period. Obviously the British government was formulating this agreement from the perspective of an advantage to the textile factories in Yorkshire, Manchester, and Liverpool. The consequence of the 1929 agreement was the distribution of the natural flow of the Nile, estimated at 52 billion m^3/year, between Egypt (48 billion m^3/year) and Sudan (4.0 billion m^3/year). The remaining 32 billion m^3 of the natural flow at Aswan (estimated as 84 billion m^3 per year) was allowed to flow unused to the Mediterranean every year. The policy was meant to show the potential of land reclamation in Egypt and concluded that more than seven million feddan could be brought under economic cultivation. This was the sum of the existing land area under perennial irrigation, plus the lands which could be converted from basin to perennial irrigation, plus desert lands located on the fringes of the flood plain in the Nile Valley and Delta and/or the waterlogged lands running parallel to the Mediterranean in the northern part of the Nile Delta.

The 1933 water policy marked the second increase in height of the Aswan Dam, (increasing its storage capacity to 2.5 billion m^3) and the start of the construction of the Gabal Awlia Dam in Sudan which made about 2.0 billion m^3 of water per year available for use in Egypt. These two events took place in the year 1932. The additional quantities of water enabled the country to convert more than half a million feddan in Upper Egypt from basin to perennial irrigation, reclaim more than 400,000 feddan in the east, middle, and west Delta, and increase rice cultivation from 200,000 to 350,000 feddan annually.

The 1953 water policy was developed to make use of the additional quantities of water made available following the increase in height of the Owen Dam in Uganda. The construction was partially financed by Egypt. The plan was to increase the cultivated area from about 6.1 million feddan in 1952 to 6.5 million feddan in 1959.

The 1959 water policy came as an immediate result of signing the Nile Water Agreement with Sudan in preparation for the construction of the High Aswan Dam which started in 1963. As a consequence the 32 billion m^3 of flood water which use to flow to the Mediterranean was divided – 7.5 billion m^3 for Egypt (bringing its quota to 55.5 billion m^3) and 14.5 billion m^3 to Sudan (to make its quota 18.5 billion m^3). The remaining 10 billion m^3 was left for evaporation from the reservoir (Lake Nasser) every year.

Following the complete exploitation of the Nile Water, all the policies which came later concentrated on groundwater abstraction and reuse of drainage water. Shallow, deep, renewable, and fossil groundwater was exploited and the amount of recycled drainage water was increased year-on-year. It has to be stated here that the first reuse project started immediately after construction of the High Aswan Dam by allowing the drainage water of Upper and Middle Egypt to flow directly to the main course of the river. Reuse projects in the southern part of the Nile Delta followed suit.

The latest water policy of 1997-2017 took an unprecedented step towards the future. Almost the entire water budget was allocated for the irrigation of an area of almost 11.0 million feddan with any remaining water being allocated for other activities. This was a reversal of the previous policies in which allocation was made first to other activities and the remainder passed to agriculture by default. The 1997-2017 policy marked the desire of the country to use water for the development of new areas which could be used for integrated activities (i.e. agro-industry, mining, energy, industry, tourism, services, etc.). In the meantime the economic dimension was overruled by other social dimensions, such as creating job opportunities and reducing the high population densities in most villages, towns, cities, and urban centers in the country. However, the 1997-2017 policy was criticized on the basis that most of the water budget items listed were considered as paper savings – they had no realistic value on the ground. For instance, savings were assumed to come from the following interventions:

- Change of cropping patterns (mainly reduction of rice area)
- Increased reuse of drainage water
- Increased area covered by irrigation improvement projects
- Reduced amount of drainage of water flowing to the Mediterranean
- Increased exploitation of deep groundwater
- Increased use of treated sanitary sewage
- Increased use of treated industrial effluent
- Increased production of desalinated water.

Horizontal expansion in Egypt followed vertical expansion. This started with the conversion of basin irrigation areas (one crop per year) into perennial irrigation zones (two crops per year). Basin irrigation was practiced with the flood water which used to arrive during the months of September and October. The winter crops were sown after the water receded. Perennial irrigation was accomplished by providing an appropriate irrigation system which enabled cultivation of a summer crop as well as a winter one.

Other vertical expansion measures were practiced according to progress in research and the building of capacities.

Horizontal expansion started in locations where reclamation was easier and less expensive. Most of the low lying lands in the strip running parallel to the Mediterranean were reclaimed first.

Desert lands on the fringes of Nile Valley and Delta were given priorities according to the lifting head – the lower the lifting head, the better.

Water quality was also an important factor. Fresh water was the only source up to the years 1920-1930. When a water deficit was experienced (most probably because of a series of years of low natural flow), drainage water was used to fill the gap. It has to be noted that Upper Serw pumping station was constructed in 1928 to lift water from Upper Serw drain to the Damietta branch for reuse downstream.

Following the introduction of drainage water as part of the water budget, shallow groundwater was included as part of the budget as early as the 1950s.

Exploitation of both drainage and shallow groundwater became a fixed policy until pollution problems appeared. Shallow groundwater was under the threat of sea water intrusion caused by over pumping, especially from the northern aquifers. Drainage water reuse was hampered when some mixing locations were closed as a result of the heavy pollution from domestic sewage and industrial effluent. Some of the water downstream from these mixing locations was used for domestic purposes.

With the restriction imposed on drainage water and shallow groundwater, deep groundwater was included for the irrigation of 500,000 feddan in the 1997-2017 plans. This area requires a minimum of 2.5 billion m^3/year for its irrigation.

Upper Nile Projects were always part of the plans and policies. The first phase of the Jongeli canal project was 80% complete before it stopped in 1982. In this first phase 4.0 billion m^3 of water would have been saved and divided equally between Egypt and Sudan. A similar quantity would have been saved if the second phase had been completed. It is now hoped that the fruits of Nile Basin Initiative, which came to light in 1999, can be made available to all the Nile basin countries. Rainfall in the Nile basin is estimated at 1600 billion m^3/year. Of this, only 84 billion m^3/year reach Egypt and Sudan. A huge amount of water is lost in the swamps and marshlands of Bahr El Ghazal, Mashar, and other areas. Again, the return to peace in southern Sudan could revive water projects and agricultural development in this important part of the Nile basin

The 1997-2017 policy is stretching the Egyptian requirements to the limit of the possible regular supply – no water would be left for emergencies – which is not a 'comfortable' situation until and unless an extra supply is made available.

For this reason, summer and winter resorts on the north, east, and west coasts, and on the Red Sea produce their own water by depending on small desalination plants. The transport of Nile water to these places proved to be extremely expensive.

Desalination is looked at as a favorable alternative if desalination is practiced on brackish water rather than sea water with a high salt concentration. If renewable energy is used (solar, wind, waves, etc.) the cost of desalination would be comparable to the opportunity cost of transporting Nile water, especially if the distance to be moved is long.

Brackish water could always be used in the cultivation of mangroves and halophytes of economic value, or any other salt-tolerant crops for making desert lands green and productive.

It has to be mentioned that the ultimate objective of this report is to review the measures taken by the Ministry of Water Resources and Irrigation (MWRI) and the Ministry of Agriculture in Egypt. It draws on previous experiences and regional and international lessons for improving these measures and enriching the future polices and institutional setups of the country. The objective is always increased water productivity for different activities.

6.4 Worldwide experience in water policies

Having reviewed the Egyptian water policies of the last eighty years, it can be said that successive policies were 'development' based, seeking to satisfy all existing and expected future requirements, with extra quantities of water allocated directly by default to agricultural expansion.

Following the introduction of the 1997-2017 water policy, the budget was stretched to the maximum limit by adding 3.4 million feddan to the cultivated area. This brings the total area to something like 11 million feddan, or a cropped area of more than 20 million feddan. However, development based policies can no longer be adopted because the last policy was, in reality, much too ambitious.

The problem with this type of ambition is that, with the existing level of water requirements (about 6000 m^3 of water per feddan per year), 11 million feddan require 66 billion m^3/year which is far beyond the country's water budget. Decision makers assume that the deficit can by compensated for from i) the application of water saving measures, ii) improvement of irrigation in the old lands, iii) strict application of modern irrigation systems in the new lands, iv) intensive reuse of agricultural drainage and treated sanitary sewage and industrial effluent, v) a change of management options (from supply to demand, from upstream to downstream control and from rotation to continuous flow), and vi) by adopting strong reform policies.

The above tools do not include the acquisition of an extra supply of water from external sources, mainly from the Upper Nile region. However, most indicators (almost ten years after the introduction of the 1997-2017 water policy) show that the above expectations were more like paper wishes than realistic interventions that can be practically implemented on the ground.

The present situation, therefore, requires a switch from the conventional 'Water Development Policy' to a more sophisticated 'Water Allocation Policy' which requires a number of actions/ interventions which affect the distribution of the given quantities of water among different uses and different users. However, before getting to this point the country has to decide about a number of policy issues, which include:

6.5 Food self sufficiency and food security

This policy issue is a subject of debate at different levels up to the highest rank in the decision-making arena. Food security is defined as 'a situation in which all households have both physical and economic access to adequate food for their all members, and where households are not at risk of losing such access (World Food Summit, 1996)'.

Food self sufficiency means the satisfaction of food needs from domestic supply as far as possible, with minimal or nil dependence on trade. The concept of food self reliance takes into account the possibilities of international trade. It implies maintaining a level of domestic production plus a capacity to import, in order to meet the food needs of the population by exporting some major or minor products. It can be said that food self sufficiency and food self reliance supported by requisite governance (i.e. conduct of national affairs on various fronts) leads to food security. (See the International Commission on Irrigation and Drainage status paper on Global Issues Related to Food Production, Security and Trade, Sept. 2003). Other definitions of food security adopted by different international organizations are as follows:

a) World Bank (WB) definition

The definition for food security adopted by the World Bank is, 'The possibility of providing every citizen at all times with the food sufficient to carry out his/her normal activities and to maintain good health.' Food security in a country is realized when the country is capable of supplying all citizens with sufficient food through the country's trade and marketing systems even in times of development crisis, times of deteriorating production, and in spite of changes in world markets. This definition combines the holistic approach of the equal rights of all citizens to be covered, the time factor represented by the availability of food on a continuous basis, and the fact that the source of the food is not necessarily local or imported or both. It requires that there should be a strong system of marketing and trade both locally and externally.

b) Food and Agriculture Organization (FAO) definition

The FAO defines food security as, 'The realization of all citizens at all times of the physical, social, and economic capability to obtain the amount of food necessary for them to meet their human need for energy according to their nutrition preferences and to guarantee an active and healthy life.' The only difference between the FAO and WB definitions is the condition of food being a basic factor in a healthy and active life, the consumer preference, and taking the social and economic dimensions into consideration.

c) Arab Organization of Agricultural Development (AOAD) definition

The Tunis Declaration on Arab Food Security (1996) spells out the definition of food security as, 'Making available food in the quantity and quality needed for continual health and activity of every Arab citizen depending upon local production first, according to the relative experience of each Arab country to produce food commodities and making the same available for Arab citizens at the prices which are proportional to their incomes and financial capabilities.' This definition adds the quality of food to other definitions, puts the condition of giving local production a priority, and brings integration between Arab countries as a relative advantage.

d) United Nations (UN) definition

The UN defines food security as, 'The guarantee that all individuals in the community at all times are able of obtain their basic food needs both from the financial and economic points of view.' This means that, according to the UN, there should be a minimum of basic food supplies and the economic capability of all individuals to purchase their requirements of these commodities.

6.6 National and individual food security

'Total loss of food commodities' takes place when a country fails to secure its total food needs either from local production, imports, storage, or reserves. Food security can, therefore, be realized through imports or production or both, while self sufficiency is only based on local production.

National food security can be realized even though part of the population is not able to obtain enough food. Individual food security can, therefore, only be attained through fair income distribution, a rise in the standard of living, creation of employment, economic development, and other developments.

Food self sufficiency is a national indication which shows that national production is sufficient for the country's needs without imports. This does not mean that some of the sectors of the society are not able to obtain their basic needs, given their low incomes or high purchase prices or both. Food self sufficiency can be imposed through the control of imports. This may imply that average individual consumption is less than is needed. Self sufficiency is measured by the quantity of production regardless of the quality, while food security puts healthy food as a precondition.

There are three dimensions implicit in the definition of food security (and consequently food self sufficiency/reliance). These are availability, stability, and access. Adequate food availability means that, on average, sufficient food supplies should be available to meet consumption needs. Stability refers to minimizing the probability that, in difficult years or seasons, food production might fall below consumption requirements. Surplus stocks may help tide over the deficit. Accessibility draws attention to the fact that even with plentiful supplies, many people may still go hungry because they do not have the means to purchase the food they need or the public distribution system is inadequate in moving food to within reach of the needy and making it accessible. Affordability is closely related to poverty, which is often defined as 'a function of the inability to consume and invest'. Poverty in monetary terms is the threshold, responding to a minimum income level required to fulfill basic food needs food. In this way poverty is directly related to individual or household food security.

Worldwide, expansion of cultivated areas roughly kept pace with population growth until the middle of the 20th century. But, in the last 40 years cereal output doubled as a result of i) expansion of the cropped and irrigated areas, ii) increased intensity of land use (cropping intensity), and iii) increased yields as a result of improved management and high yielding varieties.

The next doubling of food production is still to come, since water and land potential is available, particularly in several developing countries. The challenge is to realize this type of increase while sustaining the natural resources base. This means that Egypt will be in a position to increase its own ability to produce food commodities and to have comfortable access to world markets where food production is increased.

Of the 53 countries on the African continent, 35 are considered as least developed countries (LDC). Nineteen of them have 35% or more of their populations undernourished. The number of LDC in Asia is only 13 and in Latin America is just one.

The total irrigated area on the African continent is about 12.7 million ha, representing 6.2% of the arable land. Egypt has almost 100% of its cultivated land under irrigation. Countries like Uganda and Ghana have only between 0.1% and 0.2% of their arable land under irrigation. Five countries, Egypt, Sudan, South Africa, Madagascar, and Morocco, account for almost 72% of the total irrigated land in Africa, while a further 17 countries include just 1% of the irrigated land. North Africa has already reached more than 75% of its potential. There is a large untapped potential in central Africa where water resources are relatively abundant, which means that substantial water resource development is still possible.

A special session, 'Integrated Water Resource Management for Ensuring Food Sufficiency and Security', of the International Commission on Irrigation and Drainage was organized during the Third World Water Forum held in Kyoto, Japan in March 2003. The recommendations of this session were as follows:

- Increased crop production by adopting an integrated water resource management approach
- Increased water availability by means of water resource development to meet demand in all sectors, especially irrigated agriculture in developing countries
- Increased area under cultivation by reclaiming waste lands and areas under irrigation by increasing storage capacities, by improving water use efficiency, and by recycling wastewater
- Adopting better and effective wastewater management for rain fed areas
- Establishment of strategies for improving water and land productivity in irrigation and reduction of the gap between irrigation potential developed and utilized
- Improved governance to elevate food sufficiency to food security status
- Introduce guidelines to involve all stakeholders in the process of integrated water resource management
- Integration of the principles of equity, adequacy, flexibility, efficiency, and economy in integrated water resource management
- Increased investment by international funding agencies and local governments for modernization, rehabilitation, replacement, and new water structures is strongly needed
- Private sector should be encouraged to invest in irrigation projects by allowing reasonable profit making mechanisms in the business.

6.7 The role of trade in food sufficiency and food security

Global trade is a dynamic and highly complicated process. It is well known that there are positive links between economic growth, openness of trade, local productivity, farm mechanization, size of land holdings, costs of production, subsidy systems, and world food prices. Trade positively impacts a number of economic and social factors, such as growth rates, income distribution, employment, life expectancy, infant mortality, and poverty in general.

A comparison of world cereal trade shows a trade surplus (export) of about 13% in the total production of developed countries, whereas developing countries show a trade deficit (import) of about 6% of their total requirements. The situation of least developed countries is serious – they import almost 29% of their requirements. They have to increase their production to keep pace with their rising populations, food self sufficiency needs, and maintain the 18% reserves needed for unforeseen circumstances. If land, water, finance for infrastructure, management capacity, and knowledge base are the constraints, then these countries will continue to be in a difficult situation.

As a large number of countries all over the world become industrialized, trade becomes inevitable. The earlier General Agreement on Tariffs and Trade (GATT) and the present World Trade Organization (WTO) were established to facilitate trade between countries.

GATT provided rules for much of the world trade between 1948 and 1994 only as a provisional agreement and a provisional organization. After 1990, the United States agricultural exports faced a steep decline. It also became apparent that the decline in agricultural commodities exports arose from the protectionist policies initiated by the same countries that started supporting an agreement that would enable free trade in these commodities. The GATT vision was found to be weak and the need for a stronger trade regime was keenly felt. Following seven and half years of negotiations, an agreement on agricultural products was finalized in the Uruguay Round (1994) and signed in Marrakech, and the World Trade Organization was set up in Geneva in January 1995. Two major features were introduced into the rules of the WTO, Trade Related Intellectual Property Rights (TRIPS) and Dumping.

TRIPS

By the middle of the 20th century, a limited form of plant variety protection (PVP) was given to breeders of a new crop. With the hybrid industry evolving, they requested exclusive rights to their research results. TRIPS now fall under WTO. It obliges all parties to make available, by 2000 for developing countries and by 2006 for least developed countries, patents for any invention – whether a product or a process, in any field of technology – without discrimination. Developing countries need to take advantage of the provisions under the TRIPS agreement to protect their genetic resources, products, and technologies as well as other interests. Developing countries need to investigate if the implementation of the TRIPS agreement would directly affect the farmers and food security of their countries.

Dumping

Markets in developing countries are often subjected to a flood of cheap consumer goods dumped by foreign producers. This raised fears that even food products may be dumped in the markets of developing countries. Under WTO rules, anti-dumping duties can be levied on those countries from which the actual imports originated during the course of an investigation, provided the domestic producer of the particular product can prove that dumping has taken place.

Developing countries adopted the following positions for negotiations:

- Resist introduction of hidden subsidies
- Initiate a proactive, not a passive role
- Request international norms on sanitary and phyto-sanitary safeguards
- Insist on closer scrutiny of the non-product specific subsidies in developed countries
- Ask for better market access for products
- Give priority to food self sufficiency as long as 50% or more the labor force depend on food production for their livelihood.

Policy-makers from developing countries should address the following three issues from the perspectives of trade and the WTO

- Current agricultural policy for agricultural development in the context of WTO
- Impact of WTO provisions on agricultural policy in the future for a given country
- Impact on small and marginal farmers and benefits derived from the current developments.

The above argument explains the necessity of taking a national stand on what the country requires, taking into consideration its water status. In the absence of clear policies, like food security, food self sufficiency, and food self reliance and the steps required for the implementation of the selected policy, people will be moving in a vicious circle. Trade agreements come at the top of the agenda; meaning that each country has to make good use of the available facilities and agreements. It is not necessary that developing countries go directly to international trade, bilateral agreements and regional agreements, like the Community of Sahel-Saharan States (Africa) experience, may offer better alternatives.

6.7.1 Present production and consumption of food in Egypt

- The Egyptian citizen gets almost 4000 calorie, 120 gm of protein, and 61 gm of carbohydrates daily. This compares very well with the actual needs of 2350 calorie and 35 gm of protein per day.
- Egypt is self sufficient in the production of rice and sorghum, but imports wheat, maize, and barely on a large scale.
- Before the last outbreak of avian flu, Egypt was self sufficient with respect to white meat, eggs, vegetables, and fruit.
- Major imports in Egypt are wheat, maize, barley, sugar, legumes, oil, red meat, fish, and milk.
- The deficit in processed food trade is about US$ 370 million, excluding raw food imports (wheat, maize, barely, legumes, etc.).
- The annual per capita share of food in Egypt is about 735 kg, of which 600 kg are agricultural crops, 120 kg are animal products and 15 kg are fish.
- Production increased continually between 1981 and 2003
    - Wheat production from 1.938 million t to 6.485 million t
    - Rice production from 1.543 million t to 4.274 million t
    - Maize production from 3.308 million t to 6.431 million t
    - Sugar production from 0.624 million t to 1.285 million t
    - Red meets production from 0.294 million t to 0.840 million t.

Food production and consumption in Egypt is generally subject to three features:

- A large and expanding deficit in the production of basic commodities, such as wheat, maize, sugar, and edible oil
- For affordability reasons, 40% of the population is not able to obtain its basic food needs. Mal-nutrition caused by lower food quality is another problem for low income citizens
- Food markets are generally unstable because of the effects of fluctuations in international prices on the local markets and the consequences of these price variations on the purchasing power of citizens with limited incomes.

6.8 Other policy options

Water policies can be based on social, economic, political, and security options.

Following are some of these options.

6.8.1 More crop per drop

In view of the increasing population and the need for a higher standard of living, yields per unit volume of water and per unit area of irrigated land need to be considerably increased. However, the ‘more crop per drop’ approach implies also ‘more revenue per drop’ which means:

- Each country has to raise crop production according to its relative advantage in order to maximize returns per unit volume of water and unit area of farm land.
- Water-saving techniques, such as lining earth canals, precise land leveling, long furrows, night irrigation, use of modern irrigation systems, change of planting and harvesting dates, change of planting methods (dry seed/ transplantation), use of one point lift, and change of management system (supply vs. demand, upstream vs. downstream, rotation vs. continuous flow, etc.) should be adopted.

- A minimal area should be cultivated with high water consuming crops especially rice, sugarcane, and banana.
- Integrated water resources management, including the integration of sources, integration of demand activities, integration of different water qualities, integration of management and control, etc.
- Strong participation of users at different levels starting from the planning stage and continuing through concept design, pre-feasibility, feasibility, detailed design, construction, operation, management, and maintenance stages.
- Change of cultivated lands from high temperate regions to less temperate ones and from regions of high conveyance and distribution losses to regions of lower losses. Manipulation of different crops to better suit different regions in these respects is also a possible option.
- If land fragmentation is a major limitation for irrigation systems in developing countries, land consolidation schemes may provide a reasonable alternative. Obviously, consolidation cannot be implemented without a number of technical, financial, economic, and social consequences taking place. These factors should be taken into consideration.

More jobs per drop

Food security depends on the strength and diversity of the economy. The economies of the WANA region that began to import increasing volumes of staple grains in the second half of the 20th century have also enjoyed extraordinarily favorable terms of trade. Water rich North America, Europe, and Australia forced down the world price of stable grains as a consequence of EU and American subsidies. For much of the last three decades of the 20th century, staple grains were imported at prices reflecting only half of their production cost in the developed countries due to this strong competition.

As an example, Egypt addresses a substantial proportion of its food needs by importing water intensive commodities. These items would have required 20 billion m^3 of water if produced locally. Egypt exports crops and livestock products which use about 1 billion m^3 of water in their production. The net virtual water in these transactions is almost 40% of the current water used in agriculture.

The main benefits of this international trade are that it is economically efficient and at the same time invisible. It is also politically acceptable because it is silent. The solution is politically controversial in that it is more effective than extending crop production horizontally. But as the solution is silent and invisible, neither the process nor its advantages enter public discussion.

The process actually enables public discussion to be controlled, as there is no evident strategic shortage of water, which is not, in fact, the case. The diversification and strengthening of the economy via more ‘jobs per drop’ is the main solution to the strategic water deficit. Further, socioeconomic development will be associated with a useful reduction in the rate of population increase.

An agricultural livelihood, which is often a poor livelihood, requires on average 10,000 m^3 of water/year. Livelihoods in other industrial and service sectors, which may be better or even much better than an agricultural livelihood, require very small volumes of water. The vast numbers employed in education, the health service, other government services, the military, police, transport, and retail services use negligible amounts of water – of the order of 1 m^3 per employee per year. Nevertheless, their incomes, often modest, enable families to be housed and fed, sometimes able them to pay for additional education and services, and otherwise operate in society and generally contribute transaction cost managing inputs to the political economy.

Industrial jobs, increasingly in the private sector, are also modest in their water requirements. Those working in these sectors use much more water at home than they do at work. A good example is Egypt where agriculture consumes 80% of the country's water budget, accounts for 20% of the GDP, and 40% of the labor force, while industry accounts for 20% of the GDP, 13% of jobs and uses less than 10% of the nation's water resources with a high proportion of this water being returned to the system.

The above argument is meant to emphasize two important facts. Under conditions of water scarcity:

Agriculture is not the most favorable consumer of water with respect to job creation. Other activities could be very much better. However, if other activities are not demanding labor, while agriculture is, then agricultural employment is certainly better than unemployment.

If agriculture is the only available choice, preference should be given to labor intensive crops, labor intensive irrigation systems, less water consumption, and less energy consumption. The preference should include the choice between farm crops, livestock, and fish farming.

More stake per drop

The 1990s witnessed a rapid rise in global concern regarding the economic and environmental value of water. This concern followed from the 1992 World Summit on Environment and Development, held in Rio de Janeiro, the associated preparatory meeting in Dublin, and, eventually, the Johannesburg meeting of 2002. Subsequent international meetings led to agreement on the principles captured by the phrase Integrated Water Resources Management (IWRM). While IWRM is, to a small extent, a technical and economic process, it is largely political. Integration in itself is very political since it may be possible, with great difficulty, within one organization, but between organizations, it is extremely difficult.

Management is also political, as it is often about the allocation of resources. It is the opinion of some experts that IWRM should be called Integrated Water Resources Allocation and Management in order to signal its non-technical nature and its association with transaction cost management rather than with technical measures.

An important element of IWRM is that it includes the principle of participation which enhances stakeholder involvement and commitment and, as a result, the collective good.

Attracting stakeholders to IWRM will add power to the water policy equation. A misleading starting point is to assume that solutions lie mainly in the water sector. There is clear evidence that, strategically, water issues can only be solved outside the water sector and in the economy at large. This conclusion strengthens the idea that the larger the number of stakeholders the more effective and efficient will water use be.

More care per drop

The main impacts on the water environment, on water quality, wetlands, and coastal waters are the consequences of water consumption in agriculture. In an arid environment it is normal that more than 80% of the water be diverted to irrigated farming. It is also normal for those managing the water resources in arid zones to assume that water which is not used in crop production and productive livestock is water lost and, therefore, an economically negative outcome. Taking more 'care per drop' requires that the services provided by water in the environment are given a certain priority. Good examples are:

- Water quality in lakes, pools, and natural lagoons
- Sea water intrusion issues and their effects on soils and groundwater
- Minimum environmental flows especially under closed basin conditions
- The status of migrating birds in relation to inland water bodies

- Leaching of pollutants and toxic elements from soils, canals, and rivers
- Separating high quality water networks from low quality water ones
- Preservation of natural wetlands and other water bodies.

Part of the water budget needs to be allocated for recreation and green parks, cleaning dusty streets, washing buildings, and generally improving the scenery of villages, towns, and cities.

6.9 Benchmarking

Benchmarking is defined as, 'A systematic process for securing continual improvement through comparison with relevant and achievable internal and external norms and standards.' Benchmarking seeks to bring about improvements in the performance of organizational processes using experience gained from the study of similar organizations or processes. The target is to identify the gap between current and achievable performance and make the changes necessary to realize higher standard of performance. This can be driven by several factors, some of which are:

- Increases in population leading to a need for greater agricultural production
- Growing water scarcity leading to a need for irrigated agriculture
- Higher expectations for crop yields
- Higher expectations for the level of irrigation service
- Change of perceptions, attitudes, and practices within government agencies with respect to the provision of public services
- Change of perceptions within society on the role and standard of government service.

Benchmarking originated in the corporate business sector as a means of gauging and subsequently improving the performance of some companies in relation to their key competitors. By studying key competitors' outputs and the processes used to achieve those outputs, many organizations have been able to adopt best management practice and enhance their performance.

In some cases, organizations have done so well that they have, in turn, become the organization that others use as a benchmark. Irrigation and drainage are mainly services for irrigated agriculture. They provide or remove water to suit the crops' needs. Therefore, it is in the best interest to improve the level of service provision to water users, thereby enabling them to maintain or increase agricultural production. Three characteristics need to be borne in mind with respect to benchmarking of the irrigation and drainage sector:

- Service providers operate in a natural environment
- Irrigation and drainage entails complex and interacting physical social, economic, political, technical, and environmental processes
- Performance of irrigation and drainage schemes is site specific.

6.9.1 Benchmarking principles

Benchmarking can be divided into two parts – part one involves finding out and part two involves taking action. The two parts are divided into the following six stages:

For part one

- Identification and planning: determining the purpose of the benchmarking, the areas to be benchmarked, against whose performance is the benchmarking to be conducted, and what are the performance indicators
- Data collection: day-to-day data, data for comparison, and data collected for diagnoses
- Analysis: gaps, causes of gaps, action required to close gaps.

For part two

- Integration: introducing changes into the operational processes and procedures
- Action: processes and procedures put into place to bring about the desired change
- Monitoring and evaluation: measurement of performance against target norms and standards.

6.9.2 Use of artificial neural networks (ANN's)

The previous discussions revealed that reaching a single water policy which provides the optimum solution for all problems appears to be extremely difficult, if not impossible. Several attempts to reach such a solution using mathematical modeling, decision support systems, and many other techniques, which are based on predefined rules or equations that give a clear definition of the problem, were carried out. The problem must be presented in a way which explicitly defines step-by-step the tasks to be performed to achieve the required results. However, there are many practical cases for which the rules are either not known or are extremely difficult to express mathematically because there are too many factors involved and a large number of alternatives that need to be simulated. Reaching a preferred water policy which satisfies the needs of different stakeholders and fits with the requirement of the existing generation and the ambitions of future generations appears to have these types of characteristics.

An ANN is an information processing technique that is inspired by the way biological nervous systems, such as the brain; process information. The key element of this technique is the novel structure of the brain as an information processing system. It is composed of a large number of highly interconnected processing elements (neurons) working in harmony to solve specific problems. ANNs, like humans, learn by example. An ANN is configured for a specific application, such as pattern recognition and data classification, through a learning process. Learning in biological systems involves adjustment to the synaptic connections that exist between neurons; this is true for ANNs as well.

ANNs have received increasing attention in the last two decades. They comprise one part of the spectrum of the computational tools of artificial intelligence, but in many ways can be viewed as pattern recognition systems or as an extremely powerful multi-dimensional surface filling tools. They are extremely helpful in situations where the rules are either not known or are very difficult to specify, i.e. where it is not feasible to formulate a traditional predictive mathematical model. The major attributes of an ANN are:

- Their capability to generalize by being trained on a series of examples without knowledge of the underlying rules and to produce meaningful solutions.
- Data used for training can be theoretical, experimental, empirical, or a combination of these, derived from good and reliable past experience. Training data can be evaluated, verified, or modified by human experts to inject human intelligence and experience.
- They takes account of factors which are not easily quantifiable (non-numeric).

The above attributes are part of the reason that ANNs have become the favored tools for producing a water policy, which can be trusted by all stakeholders and meets the requirements of the Egyptian population, not only those of the present generation, but those of coming generations as well.

The ANN technique was used to predict the expected local production, the expected consumption, and the expected gap between production and consumption for three major grain crops, wheat, maize, and rice for the period 2006-2021 based upon estimates of population and crop productivity. Local, regional, and worldwide changes in trade surpluses and deficits, technology transfers, cost of labor, seeds, agro-chemicals, etc., water duties, and many other variables were all taken into consideration. Training data included records covering the period 1986-2000.

A previous exercise had shown that if Egyptian policies followed the 'business as usual' format, the problems would never be solved; more probably they would be exacerbated. Therefore, non conventional policies had to be thought of. Some of these policies are structural and some are nonstructural, some need hard interventions and others need soft interventions.

6.9.3 Structural policies

Structural policies include continuing with the existing programs of renewal of major infrastructure, including grand barrages, major control structures, conveyance and distribution systems, and the implementation of irrigation improvement projects at the farm level.

The implementation of the Upper Nile projects needed to capture the water lost by evaporation and seepage could certainly add to the overburdened water budget. In the absence of full cooperation with Nile riparian countries, there can be no positive movement in this direction.

Desalination of sea and brackish water stands as one of the most favorable tools in satisfying national needs, at least for domestic and industrial use at the present time and for the near future. When the technology is mature enough, agriculture may also be added to the list.

Rain and flash flood harvesting structures should also be provided in relevant areas, such as the northwest and east coasts, the Red Sea, and the Sinai peninsula.

Groundwater in desert areas should be used only for domestic purposes, the production of high return cash crops, mining, energy, tourism, industry, and any other services. The use of such a precious, non-renewable resource for irrigation of farm crops appears to be a very modest output. Ideas, like intermediate reuse of drainage water; and merged irrigation and drainage systems which limit drainage reuse on the local (farm) level, appear to solve some of the problems of deteriorating water quality. This idea requires the provision of a large amount of infrastructure. It is simply an attempt to keep pollution within the boundaries of well defined commands and not to export it anywhere else. The alternative is to completely separate clean and dirty water. The requirement in this case will be mainly for closed networks of open channels or closed conduits plus the control structures. The two separate networks would run both north-south and east-west, which appears to be fairly expensive solution.

Increase storage capacity by deepening and widening the Toshka depressions, Lake Qaroun, Wadi El Rayan lakes, Lake Wadi El Natroun, Qattara depression, and the coastal lakes (Manzala, Borollos, Edko, Mariout, and Lake Bardawil). This would help in receiving any additional flows from any source.

6.9.3 Non-structural policies

Non-structural policies are based on soft interventions at the top of which comes change of cropping pattern. Egypt, as explained earlier, can never reach self-sufficiency in food and fiber commodities. The country's relative advantage lies in the production of high value proxy and export commodities. In such a case, food security and food reliance can easily be attained since high value cash crops cultivated on small areas of land can cover the cost of large amounts of other farm crops available in plentiful supply in the world markets. The decision here would be on the required area of crop and the ability to market the production in a professional way. Reserves of strategic commodities have to be built up according to market circumstances in order to cater for any unforeseen variations in international market prices. This has to be done through government circles with close cooperation between politicians and senior experts in the relevant ministries.

Matching irrigation supply and demand comes second in the list of priorities since it is one of the major water saving measures and is very low cost. All it needs is accurate mapping and computer sets. The estimated initial and running costs for these are very modest. However, it gives decision maker in the master station (MWRI) a clear picture of the required water supply to agricultural land on a day-to-day basis, obtained from actual conditions on the ground. Again, full cooperation between the staff of the MWRI and that of the Ministry of Agriculture is of paramount importance.

There should be more in-depth investigation of the possibility of increasing winter cultivation at the expense of summer crops, which consume twice as much water as the winter ones. This simply means that the cultivated area in winter could be doubled if half this area is not cultivated with a summer crop. The consequences of such an intervention should be investigated in-depth (soil salinization, labor, etc.).

Crop pattern modifications should also be expanded to the south/north criteria. 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 drastic change in sugarcane/sugar beet 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 an important question to be answered. Revolutionary ideas about changes in cropping patterns are a must.

Maintaining a healthy relationship with African countries, in general, and Nile basin countries in particular, may lead to agreements enabling some countries to raise some crops, with the help of Egyptian expertise, under the favorite conditions of an ample water supply and open space.

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.

With dramatically increasing population growth, agriculture has to accept leaving a part of its share of water for other activities. It is obviously much better if such decisions are well planned ahead of time. If these decisions are delayed until the last moment, then the wrong actions might be taken.

The operating rules of the High Aswan Dam reservoir (Lake Nasser), particularly those governing the optimum storage elevation, could affect positively or negatively the amount of evaporation from the lake, thus saving or losing large amounts of fresh water. The storage of crops may prove to be more feasible than the storage of water, in the opinion of some experts.

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

6.10 The proposed water policy

Estimates of the Egyptian population by 2050 suggest that it will exceed 100 million. At the present level of per capita share of municipal and domestic water supplies, the country will need a minimum of 10 billion m^3/year. Growing industrial development will require an almost similar quantity. Agriculture will be left with between 30 billion m^3/year and 35 billion m^3/year. If, by 2050, the area of cultivated land is as planned (11 million feddan at a cropping intensity of 200%) this amount of water will not be sufficient unless drastic changes take place. This is because the average irrigation water quantity per feddan would be 3000 m^3/year; half as much as the existing level of 6000 m^3/feddan/year.

It seems as if now is the right time to take important decisions with respect to the country's future water policy. Certainly, Egypt cannot continue with a water development policy defined as, 'Actions affecting the increase in the quantities of water available for distribution and use', which has applied until now and was geared at satisfying all the expected future requirements with extra quantities of water allocated directly by default to agriculture. This is simply because agricultural requirements have now reached the limit where, unless additional quantities of water are made available to increase the water budget, agriculture has to allow for other activities to take from its share. In other words, the country will move in the direction of a water allocation policy where actions will be taken to distribute the given quantity of water among different users and uses.

Allocation will be based on IWRM and in this case slogans like 'more crops per drop', 'more jobs per drop', 'more stakes', and 'more care per drop' will come into the picture. For the 'more crop per drop' approach, the country has to consider seriously questions of the following nature. How can the cropping pattern be divided between different agro-climatic regions, between human nutrition, animal feed, and fish farming, and between old lands and new lands?

Egypt is one of the few countries in the world where a large variety of crops can be raised. A good example is the production of sugar from beet in the north and from cane in the south. The southern part of the country is known for its high evaporative demand, which adds almost 50% to crop water requirements. However, the region is known for its perfectly clean water. It is very close to the source of the water, meaning that conveyance and distribution losses are minimal. It is possible to raise the cropping intensity, especially of some vegetables. It is suitable for raising off-season crops which can be marketed as a monopoly with very little competition from neighboring countries. Yet, the distances involved in transporting agricultural commodities to markets are too long. The export of such commodities requires Red Sea transportation to the Gulf area or air freight to other parts of the world. The area of cultivated land in Upper and Middle Egypt stands now at 2.5 million feddan which will be increased to 4.0 million feddan after the reclamation work of the South Valley Project comes to an end (expected by 2017).

The climatic conditions in the Nile Delta are much more favorable than those in the Nile valley. The maximum temperature of 35°C is a lot less than that in the south which may reach 42°C. Support and infrastructure in the Delta are much better and the area is connected by an excellent network of roads, seaports, airports, and railroads. Again, it has to be emphasized that Egypt is located in the middle of the world between east and west, between Europe and Asia, and between Asia and Africa. Probably, this makes the distances to be travelled to the other parts of the world shorter than those from any other country. However, being a long way from the water source means that transport and distribution losses are higher and, most importantly, the water is partially polluted when it reaches its destination. The continuous recycling of water in the Delta results in it being of unacceptable quality at the end of the system in many cases.

This comparison shows how important it is to answer the following questions:

- Is the existing cropping pattern the best for the country?
- Is the distribution of this cropping pattern between north and south and between east and west optimal?

- What are the changes that can be made in order to achieve the maximum economic return from a unit volume of water and a unit area of land?
- Is this going to change the status of the country from self sufficiency or self reliance to only food security?
- What is the effect of continuously encroaching on agricultural land?
- How can the country make better use of the export facilities given by the European Community on the one hand, and by the rich Gulf area on the other?
- How can the country attract both local and foreign investment for the production of food commodities?
- How can the country employ modern techniques to increase productivity and raise production standards?
- How can the country reduce the pollutant loads in soil and water?
- How can the country use the Nile basin, the Common Market for Eastern and Southern Africa, and the African continent as a whole as markets for its commodities?
- Is it possible for Egypt to sign agreements with other countries to cultivate land in those countries given that they have a plentiful water supply and Egypt can offer expertise of manpower and possibly part of the investment?
- Is it possible for Egypt to expand horizontally and allow for winter crops in an area larger than that allocated for summer crop as one summer crop consumes enough water sufficient for two winter crops? If this is the case, what would be the effect on soils and manpower?
- Can Egypt make use of the food industries migrating from Europe as a result of EU regulations applied to the new member countries and how can the country make good use of these changes?
- How can the country benefit from WTO rules and is it possible for all local production be exported (obviously only the first class products, while other grades would be marketed locally) while the requirements for commodities in which the country has no relative advantage are met through imports? How can the country establish this balance?
- How can the country use agricultural products as the basis for a stronger agro-industry, which adds value to raw products and increases their market prices, and which employs more domestic labor?

Having reviewed the previous water policies, experiences, and practices, adoption of a new policy is simple because of the rich heritage of knowledge. Yet, it is also difficult because of the complexity of the problem and the huge number of factors it includes. However, in order to reduce the level of complexity of the problem, it is worthwhile splitting the factors involved into groups as follows:

- Development of new water resources

  Upper Nile conservation projects
  - Jongeli canal
  - Bahr El Ghazal
  - Mashar
  - Ocabo Oboco

  Desalination plants
  - Sea water
  - Brackish surface (drainage) and groundwater
  - Solar energy
  - Wind energy

  Rain harvesting
  - Northwest coast
  - Northeast coast
  - Flash floods in the Red Sea and Sinai peninsula

  Groundwater
  - Shallow, renewable reservoirs (Nile valley and Delta)

- Deep, non-renewable reservoirs (limestone and Nubian sandstone)
- Coastal reservoirs
- Brackish water reservoirs

Savings resulting from increased efficiency

- Improvement of irrigation networks (lining, aquatic weed, gates)
- Improvement of on-farm irrigation efficiency
- Reduction of tail end losses (night irrigation)
- Reduction of evaporation losses (night irrigation)
- Official and non-official reuse of drainage water
- Improvement of the efficiency of potable water supply networks (treatment plants, pipelines, in-house)
- Change of irrigation methods (improved surface, sprinkler, drip)
- Control of horizontal expansion

Management policies

- Operating rules of Lake Nasser
- Allocation rules among stakeholders
- Conjunctive use of surface and groundwater
- Supplementary irrigation in marginal lands
- Integrated water resource management
- Establishment of independent hydrological basins

Agricultural policies

- Matching irrigation supply and demand
- Cropping pattern modifications
- Uncontrolled urbanization
- Subsidy and taxation
- Marketing and trade (exports)
- Pricing of agricultural products
- Cost recovery
- Incentives and penalties
- Capacity building

Environmental management

- Sanitary drainage treatment plants
- Potable water treatment plants
- Improvement of land drainage
- Restricted use of chemical fertilizers and agro-chemicals
- Water quality management plans

Strategic decision making for sustainable development should select the policy that best satisfies a number of criteria namely:

- Maximize standard of living and quality of life
- Achieve social equity and peace; benefits are uniformly spread over the population
- Maximum economic efficiency; maximum output of cost-benefit ratio
- Guarantee environmental sustainability; smallest ecological footprint
- Country security (water, food, fodder, fiber)
- Financial and political feasibility (least public expenditure and political discontent)
- Maximum macro-economic attractiveness; higher gross national production growth.

In order to tackle this large number of conflicting objectives, it is necessary to use a multi-criteria decision support technique within a powerful tool, such as a decision support system (DSS). Such a system can handle the large number of parameters relevant to decision makers, the socioeconomic life of the population, and the technical system performance.

The proper use of the DSS should be to support 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.

Unfortunately, time only allowed for the first steps in the development of a DSS for the complete hierarchy of the irrigation and drainage systems. The following phase may result in a detailed study in this direction.

6.11 Institutional setup of the water sector in Egypt: the past, the present and the future

6.11.1 The past

Since the dawn of history, Egypt has established institutions capable managing, distributing, and equitably dividing water which facilitated creation of the first regular state in the world. In the age of King Minus, who united Upper and Lower Egypt, the left embankment of the River Nile was raised. Later, in the age of King Sizostrees, the right embankment was also raised. The two embankments protected the country from floods and enabled the use of flood water to fill the basins and enrich the cultivable land with the fertile sediments that had been transported by the river. Storage of water in the Fayoum depression was also reported during this age. All related activities were only possible because of the involvement of the Egyptian population, which was obviously, in some cases, forced to provide free labor to the pharaoh, the king, and even the gods.

Recent history talks about storage in the Aswan reservoir which was constructed at the beginning of the 20th century. This was followed by a series of control structures, vast network of conveyance canals, the use of water lifting devices, and the first set of legislation needed to regulate water abstraction, maintenance of irrigation canals, and penalties against those who misuse water, pollute it, or generally break irrigation laws. This was applied by qualified personnel who belonged to a central organization sub-divided into smaller authorities covering the whole country, but following the instructions of the central leading entity, what is now called the Ministry of Water Resources and Irrigation (MWRI).

In late 18s, a Royal Decree was issued stating that all men between 15 and 50 years of age were required to assist in canal cleaning. Exempted from this service were students, teachers, religious leaders, skilled labor, security officers, soldiers, and inhabitants of cities and towns who do not own land or practice agriculture. If anybody wanted to be exempted from this obligation he had to offer a substitute or pay 120 piaster (EGP 1.2), if he was a Delta resident or EGP 0.80 for Upper Egypt residents.

In 1920, the Egyptian Government issued a proposal to raise the water supply to 50 billion m^3 to Egypt and 6 billion m^3 to Sudan. In order to reach these figures, the Aswan Dam was to be raised and its storage capacity increased to 5 billion m^3, (from 1 billion m^3 at the time of construction to 2.5 billion m^3 when its height was first increased). Included in the proposal was construction of the Gabal Awlia Dam on the White Nile south of Khartoum and the Sennar Dam on the Blue Nile, storage in Lake Tana, and the implementation of the Junglei canal project in southern Sudan.

The 1929 Agreement between Britain, as an occupying authority of the Nile basin countries (Sudan, Kenya, Tanzania, and Uganda), and Egypt came to an end as suggested by joint teams representing the two parties and an international consultant, which confirmed the historical right of Egypt to Nile water. There was also a clear objection to the building of any structures on the river which might restrict the flow of water to the north (i.e. to Egypt).

The first official institution was established in 1844 and named ‘Diwan El Ashghal’, that is, the Department of Works. Twenty years later, the name was changed to ‘Nezarat Al Ashghal Al Omomiah’ – the Department of Public Works. A few years later, it was changed to the Ministry of Public Works. In 1964, it was replaced by the Ministry of Irrigation. In 1987, the name was again changed to the Ministry of Public Works and Water Resources and finally the name was changed to the Ministry of Water Resources and Irrigation (MWRI).

These frequent changes in the name of the ministry give the impression that the mandate and duties of the ministry were not fixed, but were subject to continuous modifications, alterations, and amendments.

As examples of this consider the following:

- The Department of Survey, formed as part of the ministry in 1898, was transferred to the Ministry of Finance in 1905, back to the Ministry of Public Works in 1953, to the Ministry of Defense in 1973, and finally to the Ministry of Irrigation in 1975.
- The Department of Railways was transferred to the Ministry of Finance in 1912 and to the Ministry of Transportation after that.
- The Department of Agriculture became the Ministry of Agriculture in 1913.
- The Alexandria sea port was transferred to the Ministry of Finance in 1919.
- The Department of Ancient Monuments and the Opera House was transferred to the Ministry of Education in1929.
- The Egyptian Zoo and Fish Park was transferred to the Ministry of Agriculture.
- The Department of Electricity and Gas was transferred to the Ministry of Electricity and Energy in 1864.
- The Department of Sewerage was transferred to the Ministry of Municipalities in 1950.
- The Department of Construction was transferred to the Ministry of Housing in 1950.
- The Department of Deserts was transferred to the Desert Development Authority in 1959.
- The Department of Inland Navigation was transferred to the River Transport Authority in 1959.
- The Meteorological Office was transferred in 1971 to the Ministry of Defense and to the Ministry of Transportation after that.

The idea behind the previous inventory of Departments, Divisions, and Sections which used to belong to the Ministry of Irrigation for various periods shows that the ministry was responsible for almost all utilities, works, projects, and programs of major activities – irrigation, agriculture, housing, roads, potable water supply, sanitary drainage, electricity, energy, etc.

This reflects the large degree of centralization which characterizes the performance of the ministry and which continued to influence this performance throughout the years.

6.11.2 The present

At present, the MWRI consists of the following main departments

Irrigation Department)

This comprises the following major sectors of the ministry:

- Irrigation sector
- Horizontal expansion and projects sector
- The sector of grand barrages
- The groundwater sector
- Nile protection sector
- Irrigation improvement sector.

About 2000 engineers are involved in the activities of the Irrigation Department and they are in charge of water distribution, maintenance, renewal and rehabilitation of water structures, irrigation improvement, infrastructure of new reclamation projects, etc.

Mechanical and Electrical Department (MED)

The MED is the body responsible for lifting irrigation and drainage water in addition to the lifting devices needed for groundwater abstraction. The number of pumping stations which fall under the responsibility of MED is of the order of 1600 and they are spread all over the country. MED is divided into five departments, Upper Egypt, Middle Egypt, Eastern Delta, Middle Delta, and Western Delta.

Drainage Department

The Egyptian Public Authority for Drainage Projects (EPADP) is responsible for the implementation of open and subsurface drainage projects as well as the maintenance, rehabilitation, renewal, and replacement of existing ones. Around 700 Engineers are employed in EPADP.

High Aswan Dam and the Aswan Reservoir Department

The responsibility of this department is the operation of High Aswan Dam and Old Aswan Dam governing the storage in Lake Nasser and power generation. A daily inspection of the bodies of the two dams and their surroundings is also part of the department's obligations.

Department of Survey

Responsible for the establishment of topographic survey maps and benchmarks and sharing the development of land use maps, etc.

Department of Shore Protection

This department is responsible for research, studies, design, and implementation of all coastal zone management and protection in the Egyptian territories.

Planning sector

This sector is responsible for planning for all ministry departments with reference to both water and financial issues.

Nile water sector

The Nile water sector is in charge of the Nile levels from external sources up to Lake Nasser It is responsible for negotiation with the Nile basin countries, planning for future Nile projects, and coordinating with local organizations associated with Nile water (Ministry of Foreign Affairs, etc.).

National Water Research Centre (NWRC)

The NWRC is the research arm of MWRI and includes twelve institutes specializing in: drainage, development of water resources, hydraulics, channel maintenance, water management, construction, groundwater, Nile survey and shore protection, mechanical and electrical, environment, and climate change. A first class central laboratory is part of NWRC as well.

Training center

The Regional Center for Training and Water Studies (RCTWS) is the organization in charge of continuous and on-the-job training within MWRI. All levels of engineers, technicians, administration, and personnel staff are trained on different aspects of water covering almost all the activities carried out by the ministry. In the meantime RCTWS acts as the training body for water engineers from Nile basin countries, the Middle East, and North Africa.

It is clear from the large number of departments, divisions, authorities and organizations in MWRI, and the large number of engineers involved in water conveyance, distribution, management, and operation and maintenance, that the system is extremely complex. It requires a clear understanding of the role of each institution and how the different roles can be changed, upgraded, and/or improved to be compatible with the latest developments in the water sector in Egypt while, at the same time, coping with the rapid developments and changes occurring in the world.

6.11.3 The future

For ten years MWRI worked on an institutional reform plan directed mainly at strengthening the involvement of stakeholders in the water sector and reducing the responsibilities of the ministry on the following levels:

- In the old lands: establishment of water boards at the district level or higher

- In the new lands and mega projects: various modes of private sector participation
- Privatization of some parts of MWRI (e.g. pipe factories)
- Coordination of decentralization and privatization projects and programs in such a way that:
    - These projects and programs are a coherent part of the overall institutional reform process
    - These projects and programs support each other
    - These projects and programs work together.

The vision and strategy for MWRI institutional reform as issued in May 2005 are as follows:

The MWRI is charged with ensuring the sustainable, equitable, and efficient use and development of Egypt's water resources. Traditional methods of supply augmentation, and centralized finance and administration enabled MWRI to serve Egypt's water users well in the past. However, emergent challenges call for new approaches to water management. These challenges include:

- Reduced availability per capita, as population and demand grow, with few prospects for additional supply
- Diversion of Nile supplies to large and ambitious new lands development projects
- Increasing water pollution
- Increasingly individualized cropping patterns, which call for more finely-tuned allocation and distribution
- Significant needs for rehabilitation and improvement
- State budgetary constraints.

While there remains room for efficiency and equity improvements through the application of information systems, technology, and communications, water management in the 21st century also requires fundamental institutional reform. Institutional reform is change in the distribution of responsibilities and authority among stakeholders. Water sector institutional reform is necessary because the challenges of 21st century Egypt's water resource management (WRM) can only be met by a greater involvement of water 'end-users' and an increasingly multi-sector approach to water resources planning and control.

The purpose of this MWRI Institutional Reform Vision/Strategy document is to set out MWRI's vision of the 'shape' of future sector institutions in a manner which clarifies the new stakeholder roles. The approximate horizon for the reform is 15 to 20 years. The document also sets out the major implications for the sector's legal and financial frameworks, and lists key milestones and implementation steps.

Vision and strategy development was managed by the MWRI's Institutional Reform unit, with technical assistance provided through Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ) and the Royal Netherlands Embassy in Cairo. The vision and strategy were developed in the course of three 3-day workshops with a large group of senior MWRI officials, between August 2004 and January 2005. The vision/strategy document is intended to provide a basis for discussion and is subject to modification as necessary by the wider stakeholder community, including other Government of Egypt ministries, various categories of water user, and for orientation and implementation planning within MWRI.

The objectives of the reform are:

- To ensure that the quantity and quality of Egypt's water resources are sustained for use by future generations
- To achieve a more equitable allocation of the benefits and costs of water service provision
- To achieve greater efficiency in the

allocation, distribution, and application of water.

Strategy development was guided by eight principles:

- Participation **–** increased responsibility and authority for users
- Decentralization **–** delegation of MWRI's operational responsibilities to horizontally integrated local MWRI administrations
- Basin organization **–** adoption of hydrological unit boundaries for management and administrative units wherever possible
- Water quality **–** pollution control and prevention as an integrated dimension of water management
- Private sector participation **–** increasing the demand for private sector investment and services and facilitating their supply
- Privatization **–** divestiture, where feasible, of non-essential MWRI assets and activities
- Cost recovery **–** transfer of financial responsibility to users along with management responsibility, recovery of selected main system operation and maintenance (O&M) costs, and partial recovery of selected local land improvement costs
- Inter-ministerial coordination **–** establishment of a National Water Council to ensure policy and program coordination, strengthen laws, and improve enforcement.

The eight strategies are applied to different degrees and in different combinations in Egypt's three main water management contexts, the old lands of the Nile valley and Delta, the groundwater-based areas of Egypt's deserts, and the 'new lands' developments of Toshka and north Sinai.

The old lands consume most of Egypt's water, have the largest number of users, the greatest diversity and inter-penetration of water uses, and face the greatest threats from pollution. Given the complexity of the old lands' WRM issues, the reforms have been designed as a two stage process. The first stage of the reforms involves:

- Formation of water users organizations (WUOs) at branch canal, district, and directorate levels to propose water distribution plans, participate in O&M activities, resolve internal conflicts, and assume responsibility for selected O&M costs
- Horizontal integration of MWRI administrations at district, directorate, and regional levels, and implementation of information systems for allocation, planning, flow, and quality monitoring and cost accounting
- Increased private sector participation in O&M
- Formation of the National Water Council.

The second stage of the old lands reforms involves:

- Transfer of O&M management and financial responsibilities to WUOs
- Restructuring of MWRI local administrations into Regional Water Management Authorities of the public service authority type with inter-ministerial boards of directors
- Increase private sector participation in the financing and operation of large irrigation and drainage works.

The reform in the desert lands is oriented toward the need to adopt practical regulatory, economic, and awareness based controls over groundwater abstraction and to ensure adequate maintenance of often dispersed water schemes. Key strategies include:

- Vertical organization of the MWRI administration into central, regional (aquifer-based), and district levels
- Creation of WUOs at the level of the individual water scheme
- Licensing and regular monitoring of aquifer levels and withdrawals

- Implementation of low cost projects and programs to support water conservation
- Encourage and facilitate user-based and/or private sector involvement in maintenance and in the installation of pumping facilities as the latter become necessary
- Adoption of full cost recovery principles.

The framework of new lands water management, which begins with a clean slate, involves radically modern water management institutions including:

- Full transfer to investors of water infrastructure, management, and costs at the secondary canal level and below
- Adoption of either technology based or economic regulatory instruments to ensure water conservation
- Development of a regulatory framework to ensure that water is distributed equitably and that charges for water management are not exploitative.

Several legal adjustments are necessary or advisable to implement the reforms:

- Law 12/1984 needs amendment to enable management transfer to, and cost recovery by, WUOs in the old lands and desert areas. Clear and detailed executive regulations need to be developed in order to ensure that the WUOs are both enabled and compelled to carry out their responsibilities
- Amendments to Law 48/1982 may be necessary to devolve water quality protection authority to regional water management authorities
- Amendments to Law 129/1947 on Public Concessions and Law 61/1958 are advisable to encourage the private sector to risk capital in significant infrastructure investments
- Presidential decrees will be needed to establish the National Water Council and the Regional Water Management Authorities.

The reform also entails changes in the financial framework of the sector. The framework involves three types or levels of user contribution:

- Cost transfer: this is simply the financial dimension of management transfer. Charges for various WUO services are assessed, retained, budgeted for, and spent by the WUOs
- Cost recovery**:** users pay for certain MWRI services, for example the O&M costs of the High Aswan Dam and the main canals.
- Cost sharing**:** users pay a share of the capital costs of MWRI investments which provide identifiable local benefits, such as branch canal continuous flow projects.

For equitable cost recovery, MWRI will adopt cost accounting systems which identify and disaggregate costs at lower and lower levels of the irrigation and drainage system down to the individual branch canal. Such accounting will enable not only more equitable charges, but also better comparison of the efficiency of MWRI units at similar levels.

Although the ‘Vision and Strategy’ was issued in May 2005, the Ministry released, in August 2008, a ‘Development and Implementation Plan’ for forming ‘Regional Water Management Administrations (RWMAs)’ in which a clear statement of the shortcomings of the water system management within the present MWRI institutions was given as:

- ‘Redundant’ and ‘conflicting’ decisions and work instructions due to the ‘complicated’ administrative structure
- ‘Poor’ decisions due to the disaggregated nature of the data and information needed for the decision making process and the many administrative barriers or conflicts of interest within organizational units
- ‘Lack’ of coordination between the water resources maintenance and development projects

- Higher costs of O&M due to ‘redundant’ activities, manpower, equipment, and facilities
- ‘Low’ participation of water users in water system management due to the ‘lack’ of and need for enabling awareness and involvement mechanisms
- ‘Little’ownership of water systems by water users leads to significant violations and encroachments
- Increased deterioration of water quality through contamination by solid and liquid wastes.

The report goes on to suggest that, “The above problems can only be overcome by a fundamental change in the existing arrangements of the water system management.” Potential solutions must include the integration and optimization of ‘scattered’ and ‘interrupted’ business processes as well as their related organizational structures.

In order to reach this target, a two phase plan was suggested:

- The first phase required the establishment of basic organizations and entities and horizontal and vertical expansion within ONE hydrologic (integrated) region.
- The second phase is meant for up-scaling and development towards a powerful entity that could strengthen integration, participation, and partnerships (at all institutional levels involving all stakeholders).

The idea behind forming a Regional Water Management Administration is to lead to the integration and combination of existing organizational units, such as the irrigation, drainage, mechanical and electrical, irrigation advisory service, groundwater, water quality, and telemetry directorates. Moreover, the RWMA will promote the creation of branch canal Water Users Associations and District Water Boards, and other expanded units, in order to fulfill its mission (regional and central).

It has to be stated, in conclusion, that the MWRI was historically, is at the present time, and will continue to be in the future, one of the most important organizations in the country. Initially its role was too large, with involvement in irrigation, drainage, housing, railroads, paved and earth road works, potable water supply, sanitary drainage, municipal activities, inland navigation, sea and river ports, public works, survey, mechanical and electrical aspects, and even the supervision of the Royal Opera House.

The nature of such a historical, central organization was maintained even after a good number of the tasks were stripped from the ministry at different times. The complicated organizational structure of the ministry at the present time, the large number of personnel involved, and the level of detail with which the ministry staff are dealing shows that institutional reform is not only appropriate, but is also imperative.

The reform is expected to address three major points:

a) How to simplify the organizational chart of the ministry based on the following assumptions:

- Reduce the number of sectors, departments, divisions, and authorities within the ministry to a minimum. A good example of this is the reduction of the research institutes in the NWRC by one-half as a first step and then to one-third
- The role of each new organization should be clearly stated
- Jobs within each organization should be clearly described
- Overlap and duplication between organizations should be brought to a minimum both within the ministry and with similar organizations in other ministries
- The role of the ministry should be limited to the tasks which cannot be done by the participation of stakeholders, private sector, and volunteering, non-governmental organizations, etc.

- The ministry should strengthen coordination with other ministries and organizations, especially those concerned with water – mainly agriculture, industry, tourism, electricity, potable water supply, sanitary drainage, media, health, security police, and justice.

b) How to reduce the number of employees in each sector, department, etc.

- This step can be implemented before the reduction in the number of sectors, departments, etc., or in parallel with it. This type of action requires the following:
- Selecting the right candidates to the right jobs according to the specified job descriptions identified earlier. This process has to be carried out in a transparent manner and the employees should be consulted and advised at different stages of the selection.
- Employees who do not have the opportunity to get a position should be posted to other divisions both within and outside the ministry, trained for other positions, or offered a fair early retirement option

c) WUAs should be strengthened through the appointment of some of the ministry staff who are in excess to actual requirements

- Egyptian expertise in water-related issues should be made available to neighboring countries, especially the Nile basin countries.
- The role of MWRI in water management has to be reviewed and modified on the following basis:
- MWRI should bear responsibility for major delivery works. Smaller canals and control structures, which can be managed by users, should be handed over to them in good condition. MWRI should continue with technical and financial assistance until farmers are capable of running the show on their own.
- Users should take over tasks like water distribution, cleaning of *mesqas* and branch canals, and the resolution of disputes
- If service providers are appointed to the boards of WUAs, the levels of participation can be raised from the *mesqa* to the branch canal, main canals, and irrigation districts
- MWRI institutions should be prepared to accommodate each step in the development and the laws have also to be compatible with each stage
- Awareness campaigns should be organized in parallel with every stage of development.

It can be concluded that institutional reform in the water sector is still a slogan. Very little has been achieved so far – little more than an awareness exercise. The big issues of decentralization, participation, public-private partnership, privatization, private sector participation, etc., are still just titles with very few facts on the ground.

The process appears to take too long a time because of the old nature of the ruling institute, their fear of losing authority and power, and the weakness of civil societies (NGOs, syndicates, members of parliament, media, etc.).

Institutional reform is part of a comprehensive reform that hits every corner and every activity in the country, including political, economic, social, and cultural.

The result of reviewing the existing institutions within the MWRI and other ministries reveals that the number of organizations in the structure of the ministry is too large and the number of employees within each organization is also too large.

It is, therefore, advisable to start with a new organizational chart in which the role of each department, division, sector, authority, etc., is well identified. In the meantime, the jobs in each of these entities need to be well described. This process may frighten those employees who may have to be transferred to other places, take early retirement, or undertake re-training to occupy other jobs which are needed by the ministry or the country.

Decentralization, as represented by the division of the country into five independent regions, is still in a very early stage of development. Although the idea is sound, the application will be rather difficult given the need to change the structure in each 'region'. This is contrary to the general position of the government, which calls for 'cuts' rather than 'changes'. For this reason the proposal to reduce the number of sectors, etc., and cut the number of employees in each sector appears to be more in line with official attitudes. The problem which remains unsolved will be that of the employees who are in excess of the actual needs of the ministry.

As long as water remains as a commodity that is given free to farmers, the idea of privatization and private sector participation in water projects will continue to be avoided. The simple reason is that private business is only successful when it is profitable. A profit cannot be made unless water is treated as an economic good.

Many countries, with conditions similar to those in Egypt (China, India, Bangladesh, Pakistan, Morocco, Tunisia, and Jordan), have a variety of water pricing systems. It appears to be common not to charge farmers the actual cost of water conveyance and distribution and the actual cost of O&M. The minimum consumption is normally charged at a very 'symbolic' tariff, which escalates with increases in consumption to a 'cross subsidy' point – charging more for higher consumption to cover the subsidy for the lower consumption. In these cases the state ends up putting no public money into the system.

The participatory irrigation management (PIM) approach is discussed in detail in a separate section of this report. The division of the country into five hydrological basins is not only important with respect to decentralization, but also with respect to the creation of self-contained catchments in which water is recycled inside each catchment and little, or no water, is exported to other catchments. The idea is to prevent or at least reduce the accumulation of salts and other pollutants and toxins through the water's long journey from south to north.

Last but not least, the establishment of a supreme committee for water provides an opportunity to superimpose general policies on different stakeholders, i.e. irrigation, potable water supply, industry, inland navigation, fish farming, and hydropower generation. Meanwhile only water of standard quality should be permitted to be disposed of to drainage canals. Ultimately it would be possible to allow for certain minimum environmental flows to be drained to the Mediterranean Sea and the coastal lakes in direct contact with it.

6.12 Participatory irrigation management (PIM): local, regional and international experience

One of the fundamentals of increasing water use efficiency is the maximum possible involvement of all stakeholders in the various management activities As water is essential to all forms of life and prosperity, competition for water among users is already escalating as growing needs outstrip the limited resources. The objective should be to convert the competition between stakeholders into a form of integration and cooperation that achieves the largest overall revenue with the least harm to the sector and division. Private stakeholder associations can act as counterweights to the government department's own technical agencies to enhance water use efficiency. Most of the developed countries adopted PIM policies a long time ago, as a matter of fiscal necessity. Farmers in developed countries have a high level of education and access to strong support services through both the private market and the public sector. It is the opposite for farmers in developing countries who are less educated, their standard of living is far below average, and their ability to hire service providers is extremely slim.

This section comprises a group of case studies and experiences in different countries to achieve the following objectives:

- Consolidate national experience in participatory approaches to irrigation management
- Learn from the experiences of countries that have successfully adopted policies to transfer management to WUAs
- Come up with suggestions on how to use regional and worldwide experience to improve the situation at the national level, upgrade the idea, and tempt both the government and users to adopt it and benefit from it.

6.12.1 Egypt

The involvement of users in water issues in Egypt is as old as the country itself. Major informal forms of participation include the following:

- *Munawba* and *mutarfa* are organizational units at the *mesqa* service area with an off take from a branch canal. A leader, the *Rais El Munawba* (the chief), has considerable authority and responsibilities for the allocation of water on a time basis, the settlement of disputes, and the carrying out of regular maintenance of the *mesqa* system. Water is allocated by time and the area served according to fixed delivery schedules, which not only change from one year to the next, but also from one generation to the next.
- The *saqia,* or water wheel, is an animal-powered lifting device. Other primitive devices, such as the *shadout* and *tambour,* were operated by humans for a much smaller lifting head than that possible with *saqias*. The *saqia* organization comprises between 8 and 12 families who own land near the *mesqa* from which the water is lifted. The land area allocated for the *saqia* installation is purchased collectively by the members who also purchase the *saqia* .The cost of operation is divided into shares according to land ownership, the cost of feeding and taking care of the operating animal, and the cost of repair and maintenance of the *saqia*. Water is allocated to members according to a fixed rotation and conflicts are resolved by the members.
- *Haqul Arab*, is a concept based on Islamic principles of fairness and equitable distribution held through informal justice, rights of appeal, detailed investigation, and stipulation of fines and sanctions. Micro system problems are resolved locally while cases involving theft, sabotage, and deliberate damage to properties or crops are transferred to the local police.

Private associations in Egypt are represented on the tertiary and branch canal level. Associations established on the tertiary level include water users associations (WUAs) on the improved *mesqas* (total number, 20,000), water users unions (WUUs) in newly reclaimed lands, and collector drain users associations (CDUAs) in tail drainage projects.

The WUAs, through regular meetings and discussions, identify the roles and responsibilities of the *mesqa* heads and set up rules to resolve conflicts, establish linkages for coordination with other agencies concerned with agriculture and irrigation, as well as with other WUAs. Members of a WUA also help in building the financial resources of the association in order to improve operation and maintenance. Nevertheless, legislation is still required to define the structure of the Water Boards and their responsibilities, especially when the members are not only farmers.

The Egyptian parliament issued Law No. 213 in 1994, where WUAs were defined as legal private organizations at the *mesqa* level in the improved irrigation systems, which are owned and operated by their members for their own benefit in the old lands.. The same Law No. 213 also introduced the water users unions, (WUUs), which are more or less defined in the same way except that these are applicable for the (old) new lands. The bye-laws of Law 213 (Decree No 14900 of 1995) detail the rights and duties of the WUAs and WUUs. In 1995, a Dutch-funded project established the first experimental WUO at the branch canal, and called it a 'local water board'

Some of the benefits achieved from the improved irrigation systems and the participation of farmers in the operation and maintenance of the irrigation system can be listed as follows:

- Increasing efficiency of water distribution in most command areas by 30% to 40% as well as maintaining equity of water distribution among all the farmers on the *mesqa*, including eliminating the tail end problem
- Reducing irrigation time by 50% to 60%
- Reducing pumping cost by EGP 25 to EGP 40 per crop (per season). Reducing the number of working pumps from 10 to 30 on the old mesqas and from 1 to 3 on the improved *mesqas* by adopting the one point lift approach on elevated and lined *mesqas* as a substitute for multiple lift points on conventional earth *mesqas*
- Reducing maintenance costs
- Transferring new irrigation technologies to the farmers through the Irrigation Advisory Services of MWRI
- A very important benefit gained is that the farmers have a better chance for resolving conflicts among themselves as they have to share a common resource
- Most important is the creation of a new spirit of cooperation between farmers through the introduction of the WUAs.
- The main functions of WUAs as listed in the Irrigation and Drainage law are as follows:
- Participation in the planning, design, and construction of improved *mesqas* (one point lift, elevated, lined)
- Operation, maintenance, and management of improved *mesqa*
- Improvement of water use activities at the *mesqa* level
- Identification of the tasks and responsibilities of *mesqa* leader and setting up rules for conflict resolution
- Establishment of links with agricultural and irrigation agencies, other WUAs, and higher level organizations on the branch canal
- Development of financial resources, operation of a bank account, and agreement on the rules for the collection and expenditure of the money.

The law defines WUAs as 'private organizations' owned and operated by members for their own benefit and work in the field of water use and distribution and all related organizational activities for the purpose of raising agricultural productivity.

In order to enable WUA members to better understand their duties and responsibilities in the early stages of their inauguration and to help them achieve the objectives of involvement, groups of technical members, named 'Irrigation Advisory Services' were established. The main functions of these groups were:

- To help farmers to setup WUAs
- Provide support in the planning, design, construction, operation, and maintenance of improved mesqas
- Assist in management transfer and conflict resolution
- Transfer technology, such as precision land leveling (by laser) and automatic gates
- Encourage farmers to develop links with Extension Services, the Agriculture

Credit Bank, Cooperative Irrigation and Drainage District Offices, pump maintenance bodies, and other local authorities.

The development of water users' participation is structured through two channels:

- CDUAs, or
- Branch canal WUAs

The CDUAs are associations which are meant to carry out routine maintenance on collector drain manholes and pipelines. They have never received legal recognition and remain as voluntary organizations.

The branch canal WUA is the next step up in the hierarchy of the irrigation system. It represents an upgrading of the WUA to a higher level. The, major differences between both levels are:

  - The *mesqa* is a private property owned by farmers, while higher level canals are public property
  - Mesqa organizations have legal status, others are not yet legally recognized
  - Social control at the *mesqa* level is a highly effective management tool; such a tool needs to be replaced by more effective rules, regulations, and sanctions at the higher levels
  - Users at the *mesqa* level generally have common interests; those at the higher levels have diverse interests
  - At the *mesqa* level coincidence with tile drain boundaries does not normally exist, while at higher levels the chance of coincidence is greater
  - The number of stakeholders at the *mesqa* level is much smaller than at the level of the branch canal, this makes holding meetings and seeking agreements more possible

- *Fayoum,* 'local' water boards, are a joint management model whereby water users and government staff (mainly the Irrigation District Engineer) are represented
- Water boards.

Water boards formed with *mesqa* leaders at the branch canal level are still in the pilot-stage and have not yet received any legal recognition. The government's rationale for the development of water boards is that i) they reduce the burden on the state, ii) promote efficient water use, and iii) ensure better water distribution. The farmers' rationale is that they i) provide effective maintenance, ii) ensure equitable water distribution, and iii) prevent conflicts.

The actual role of the water boards should be:

  - Maintenance of tertiary and secondary canals
  - Irrigation scheduling and water delivery
  - Installation, operation and maintenance of lifting pumps
  - Conflict prevention versus conflict resolution
  - Cost reduction versus cost recovery
  - Adherence to agreed upon cropping patterns versus patterns imposed and policed by the state.

The sustainability of water boards depends upon the credibility and role given to them by the state in the context of participatory water management. In order to achieve sustainability the question is whether to expand horizontally with the number of boards or vertically by proceeding to the level of the irrigation district.

It is important at this stage to review the orders of magnitude of the irrigation hierarchy from the bottom up.

  - The number of private *mesqas* is about 100,000. They serve an area of between 10 feddan and 100 feddan. The average number of farmers on each *mesqa* is 150.
  - The number of branch canals is between 4000 and 5000. Each

one serves an area of between 500 feddan and 3000 feddan. The number of farmers on each canal is between 1000 and 5000.

- The number of main canals is between 400 and 600. Each serves an area of between 15,000 feddan and 25,000 feddan. The number of farmers on each canal is between 10,000 and 20,000.
- The approximate number of irrigation districts is 300. Each serves an area of from 20,000 feddan to 60,000 feddan. The number of farmers in each district is between 40,000 and 80,000 living in from 30 to 100 villages.
- There are 26 governorates. Each serves an area of from 200,000 feddan to 500,000 feddan. The average number of farmers in each governorate is about one million living in about 2000 major and satellite villages,

In view of the difficulties experienced in transferring just O&M responsibilities, it is likely to be rather difficult to introduce a finance policy that imposes burdens on farmers, compromising their limited income. In the irrigation improvement areas, as equity and yields improved, partial self-financing of WUAs has been successfully implemented and accepted by farmers and the public. For water boards and other farmers groups, equity and yield improvement may, therefore, be pre-requisites for introducing cost recovery measures. As MWRI reduces its investments and involvement at the branch canal level, the money saved could be made available to water boards and WUAs to finance contracts for private sector involvement.

The pre-requisites for successful task transfer include i) a firm policy decision to transfer a meaningful level of responsibility for the management of irrigation systems to private associations, and ii) enhance the capability within public irrigation agencies to provide technical and institutional support to the associations.

The existence of capacity, autonomy, effectiveness, accountability, relevance, legality, and mission in the associations at the branch canal level is necessary to guarantee a successful task transfer.

In conclusion, after more than three decades of experience with user participation at different levels of the irrigation hierarchy, it has to be said that the picture is not very bright. The handing over of responsibility from a very strong bureaucracy is, as expected, very slow given the reluctance in official circles to risk a management transfer, which may or may not be successful. In addition there is reluctance on the part of the users to take the risk of managing a system which may not be easy to operate. In this type of situation it is necessary to raise the level of assurance of both sides and to strengthen their will and determination to make the transfer a success.

Past experience suggests a number of important issues:

- The government should not be very optimistic in assuming that farmers will be able to operate the system from day one on their own, and thus relieving the state budget of a burden. The funds allocated for each O&M item should be fully or partially allocated to the relevant farmers' organizations and gradually withdrawn when they are self financing.
- Farmers' organizations do not necessarily have the technical experience needed. Service providers are required to fill the knowledge gap. Retired irrigation engineers provide an excellent resource; their cost should be borne at the beginning by the state and gradually transferred to the farmers' organizations when they can afford them.
- The social, legal, and political status of farmers' organizations should be clearly identified in order for them to operate and be accountable to the state. This requires amendments in the laws and bye-laws.

- The state has to decide whether to expand the farmers' organizations horizontally (by increasing the number of WUAs) or vertically (by going to the level of branch canal WUA, water boards or district level water boards). Obviously with the higher level, the technical problems will increase and the number of government stakeholders (drinking water supply, inland navigation, industrial requirement, fish farming, etc.) will likewise increase. It is the government that has to decide on the level at which the whole process of user participation has to come to an end.
- The worst scenario would be to progress one step and retreat. It is, therefore, strongly recommended to move slowly, but surely, when moving from the pilot level to the policy scale.
- The Irrigation Advisory Services has operated as an organization different than the farmers' organization; they should merge into one body. Employment of multi-disciplinary teams (sociologists, agronomist, groundwater specialist, water quality engineers, etc.) in this respect is a must.
- Measurable indicators and well prepared time schedules should always be the first step towards the implementation of plans.
- Opportunities for the formation of WUAs inside irrigation improvement projects, or in areas where irrigation improvement is not taking place, should be identified and retained in the implementation plans.
- Transparency in the presentation of a well defined cost recovery program, giving farmers the opportunity to know what they have to pay, how, and when in advance of the opening of new *mesqas*, is essential. Cost recovery and an inability to answer farmers questions continue to be major constraints to the irrigation improvement project and create doubt and suspicion in farmers. This state of affairs makes it very difficult for the Irrigation Advisory Service staff, who are on the firing line every day.

6.12.2 Regional experience

Tunisia

The transfer of irrigation development projects to beneficiaries is based on technical, economic and social criteria. The participatory approach introduced in 1988 helped to speed up the transfer procedure, deal with the maximum number of projects, and make beneficiaries contribute to the technical selection of these projects. The simplest water distribution plan is that related to rural drinking supply; then came small and medium scale irrigation networks whose areas vary between 30 ha and 300 ha. At the level of these developments, user associations had progressively taken care of the energy costs first. Their financial involvement then extended to the salaries of pump attendants. This relieved the state of all energy and personnel costs. The Agricultural Regional Development Commission (ARDC/CRDA) still supports weak associations for major maintenance works and the replacement of equipment. In the major irrigated public areas, mainly centered in the northern regions of the country and having areas ranging between 1000 and 30,000 ha per plot, associations are formed for homogeneous irrigation entities. The average area of such an association may reach 1000 ha.

Since 1986, the idea of a collective interest association (CIA/AIC) was re-activated. It assumed responsibility for the management and use of the water of state-owned property and of the modern irrigation infrastructure set up by the state in activities related to the provision of drinking water and irrigation. This reform of the state disengagement policy led to the merger of two existing agricultural bodies and the creation of a single administrative body. The years 1987 and 1988 witnessed the appearance of regulatory texts which helped to set up the present legal and institutional framework with slight modifications. These included a law modifying some Articles of the Water Code of Law 87-3 5 which outlined the official status of CIA/AICs and stipulated the conversion of existing owner and user associations, within one year, into collective interest associations, and three decrees:

- Governing the organization, mode of establishment and functioning of the Collective Interest Association (Decree No. 87-1261)
- Concerning those of hydraulic interest groups (Decree No. 87-1262)
- Concerning the elaboration of standards and statutes of association (Decree No. 88-150).

A national strategy for the establishment and follow-up of CIA/AICs was laid down in 1990 defining the objectives and modes of support for their creation and functioning. The dissolution of development offices in 1991, whose set objectives had not been fully achieved due to the transfer of their powers to the Agricultural Development Regional Commissariats, (ADRC/CRDA), was an attendant measure urging the revitalization of the association movement. This sought to enable user groups to bear the remaining operation costs of irrigation facilities. In 1999, the new Law No. 99-43, replaced the name CIA/AIC with collective interest group (CIG/GIC) and laid down the possibility for these groups to extend their scope of activity to fulfill any mission aimed at strengthening the members' collective interests. In 2001, procedures related to the establishment of a CIG/GIC were simplified by Law No. 01-28. There had been 350 traditional associations before the institutional and legislative reforms. In 1990, 187 associations were reorganized. At present there are more than 1000 CIG/GICs, grouped mainly in the central and the southern parts of the country. They are responsible for the maintenance of water distribution networks and drinking water supply networks in rural areas, the oases, and in small and medium scale irrigated areas. These groups run 56% of the irrigated areas equipped by public investments, including some major areas. The remaining 44%, which operate in major irrigation areas, are still run by ADRC/CRDA. The Tunisian experience shows that despite their short experience, developments are moving fairly fast through the continuous modification of laws. It should be said here that system of water pricing in Tunisia is one of the most advanced in the whole MENA region. Cross subsidy is practiced on large scale.

Yemen

The participatory approach by the users generated a sense of responsibility that had not existed before. They were committed to a better use of the resources and facilities and to protecting them. Water use is more reliable and equitable to the extent that the plots situated upstream or downstream of the irrigated land are equally served. Irrigation management rules are developed and implemented by the users whereas before the transfer they were simply followers of rules imposed by the government. This self-regulation led to more reliability and less conflict among the users. All farmers are members of the WUAs, and, regardless of their political affiliation, they are served equally, which means that political influence does not play a role in service provision. The fact that users pay their bills, not the state as previously, means that equitable service and users' rights are key issue. If these are not provided the leader of the WUA is not re-elected or is obliged to resign, which means that there is social pressure against unfair application of the rules. The 'user pays approach' has increased awareness of water saving. The collection rate increased from 42% (under government control) to more than 80% (under the control of the WUOs). In 2001, the WUOs had a budget of US$ 31.7 million for expenditures on personnel (32%), energy (19%), gas, leasing, rehabilitation, and maintenance of machinery and equipment (12%), repair and maintenance of the scheme (11%), procurement (10%), and other costs (16%). Energy consumption for pumping decreased after the transfer. Having to pay the bills leads to less water use and encourages good care to be taken of the facilities. The reduction in energy use is estimated at between 25% and 45%. Some of the retired O&M staff find jobs with the WUAs. The WUOs employ 5240 persons at the minimum wage. The WUOs have managed to successfully handle conflicts among the farmers caused by the inadequacy of service roads and distribution canals.

At the end of the 20th century, the Yemeni government introduced new criteria to implement sustainable development schemes to recover the capital costs of the project's rehabilitation and to decrease the government's commitment to the O&M budget. In each *wadi*, the surface water is free and available to the stakeholders according to the rule of *Al-A'ala Fal-A'ala* (upstream users take their quota and pass water downstream). Each area adjacent to the *wadi* course permits the traditional free *wadi* off-take (FWO) system, from which farmers irrigate their lands and manage the water distribution according to its availability. For each FWO, there is one person in charge who has the power to turn the water outlets on and off and supervise the operation and maintenance of the canals and the spur in the *wadi*. The area of responsibility for the FWO varies from 10 ha to 1500 ha depending on the topography of the area and the ownership of the land. The project was launched in February 2001. The strategy for establishing the WUOs commenced in 2002 with the assistance of an international consultant. Some of the water user groups have already been formed.

Yemen is facing severe water scarcity which forces successive governments to follow whatever practice allows for better management of water as a scarce resource. The introduction of knowledgeable personnel as service providers among the members of the WUOs is an important step towards training other members in solving the water problems these organizations face.

Morocco

Voluntary, WUAs can be established either on the initiative of the government or on the initiative of two-thirds of the owners or tenants of the land served by the same irrigation system. The procedure for establishing the WUA depends on who is responsible for the initiative. Where establishment is at the government's initiative, all owners and tenants of the area under consideration are called to a general assembly by the local authorities. The government presents a program of action for the WUA and details how it would function. The WUA is legally established when the assembly adopts the program proposed by the government. The law specifies the requirements for the deliberations to be valid. If the WUA is being established at the initiative of interested owners and tenants, the general assembly submits to the government a program of action. The WUA is legally established only after the government has approved the proposed program. Existing agricultural associations (Associations Syndicates Agricoles) that are involved in water resources management for agricultural purposes are transformed into WUAs, following the procedure for the establishment of WUA at the initiative of the government.

The functions of the WUAs are specified in an agreement stipulated between each association and the government. The agreement indicates i) the area of jurisdiction of the WUA, ii) the works to be carried out and any related studies, iii) the funds necessary for implementation of maintenance and repair works, iv) the resources required for financing the works, v) the different contribution rates for the WUA and the government to cover the costs of maintenance and repair works, and vi) the responsibility of the WUA to carry out all works and to cover all costs related to the delivery of irrigation water and O&M of canals. The council of each WUA has authority to settle disputes among members. However, in case of failure, the parties can refer their case to the courts.

The WUAs impose annual dues on their members plus a special contribution to be paid for the establishment of the WUA. Annual dues are in proportion to the rights of each member and the general assembly establishes the basis for estimating dues. The government can delegate WUAs to collect government charges from their members, but the WUAs are not entitled to impose fines on members without the consent of government agencies. The implementation of PIM in Morocco has encountered several problems in the large irrigation systems. These include:

a. A lack of training

The abrupt transition from a non-participatory management system to a participatory one is being carried out with little preparation of the technical staff involved or the users. There is a problem in helping the two sides – the government administrative staff and the users – to assimilate the new set of duties and responsibilities.

b. Defining what to transfer

The management level and the specific tasks to be transferred to the Association of Agricultural Water Users (AUEAs) are still not clearly defined. The tendency is toward a progressive strategy that consists of proceeding step by step to adapt to the specificities of each case in the best way possible and to ensure the understanding and support of the irrigation users.

Cost recovery and financial sustainability

The establishment of a treasury fund for the AUEA and its renewal by the simple collection of users' contributions is not accepted by all AUEAs. In particular, asking farmers to pay for tasks previously provided by the government is problematic. Moreover, the increase in the price of water and the overall decrease in prices for agricultural products threaten the viability of farming enterprises. One possibility is for the government to provide the AUEA with the necessary technical and administrative staff until such time as the AUEA has sufficient financial resources to cover these or equivalent staff. Assuring durable finances for the activities of the AUEA is an issue that is being actively investigated at the present time.

Although the small and large scale irrigation has been practiced for a long time in Morocco, user participation is still lagging behind. The establishment of WUOs needs time and effort that can only be made available if users realize that they are going to get better a deal than that offered by the government, or when they are not happy with government service. In both cases, government agencies have to provide users with all possible support to help them help themselves.

6.13 Conclusions

In conclusion, the formation of WUOs in Egypt, their role, their merits, their limitations, and the constraints they are facing can be summarized as follows:

- User participation has been historically practiced on a wide scale through different forms of voluntary contribution including free labor and, recently, to shared facilities, such as wells, sakias, and diesel pumps.
- The state has not yet decided on the optimum level of user participation: the mesqa, the collector drain, the branch canal, the main canal, or the irrigation district.
- Both side, the users and the state, are still reluctant to move the experience from pilot to policy. From the government point of view, the possibility of the experiments failing may be the reason. From the users'

point of view, the need for an external and neutral arbitrator may be the reason.

- Despite the fact that many thousands of associations are already registered, they still do not have the appropriate legal status. For example, they cannot enter into cleaning contracts, they cannot officially stand in court cases as a recognized entity, etc. Unless this matter is resolved, such organizations cannot operate in an acceptable fashion.
- It is not yet decided, whether membership in the associations is compulsory.
- Whether or not associations are formed in irrigation improvement projects or on unimproved lands has not yet been decided.

Chapter 7: Characterization and classification of constraints to improve irrigation efficiency in the Sudan’s Gezira scheme

Chapter 7: Characterization and classification of constraints to improve irrigation efficiency in the Sudan's Gezira scheme

A. El Amin

7.1 Introduction

Sudan's economic growth is dominated by the agricultural sector's contribution and it accounts for an estimated 45% of GDP, provides employment for 55% of the labor force, and contributes to 85% of export earnings. Sudan has 127 million ha of agricultural land, of which 16.9 million ha is under permanent crops and arable land. Permanent pastures amount to about 110 million ha, and forest and woodland cover to about 43.2 million ha of land. Only 1.95 million ha of agricultural land is irrigated, mostly is using surface water.

The irrigation sub-sector contributes about 27% of agricultural GDP, and it produces most of the cotton, wheat, sorghum, sugar cane, legumes, orchard crops (sunflower), peanuts, and green forage. The contribution of the irrigated sub-sector to GDP decreased from an annual average of 17% in the 1980s, to 12% in the 1990s. This decrease arose from many factors which are related to the nature, magnitude, and pace of implementation of the economic reform policies. Poor infrastructure – mainly the irrigation systems and management, the high cost of financing, and inadequate agricultural technological packages – also contributed to the decline. Consequently, at this time, the contribution of this sub-sector to GDP does not exceed 15% in the best seasons.

The Gezira scheme is the largest irrigation scheme in Sudan. It covers about 2.1 million feddan and it is located in the triangular land between the Blue and White Niles, south of Khartoum between latitudes 13.5° and15° N and longitudes 32.5o and 33.6o E. The Gezira is a flat alluvial clay plain 25 m thick with a general slope from south-east to north-west and an average gradient of 10 cm/km which makes it ideally suitable for gravity irrigation.

The whole Gezira scheme lies within the dry zone. The annual rainfall is between 150 mm and 350 mm. The rainy season is very short, lasting from July to September. The inter-annual variability of rainfall is very high with a coefficient of variation of 30%. There is abundant sunshine and solar energy ranging from 20 million J m^{-2} day-1to 26 million J m^{-2}day-1. The annual and diurnal range of temperature is high. The diurnal range reaches 20°C in some months, while the annual range is about 10°C. The combination of low rainfall, high solar energy, and low humidity leads to a high rate of evaporation, which is estimated to be 2500 mm annually. The nominal capacity of the Gezira main canals is 31.50 M m2 /day. The peak discharge may reach 34.6 M m3 /day in October I, which is impossible for the two main canals to satisfy such requirement.

Water requirements and availability for the Gezira and Managil main canals are presented in Table 7.1.

The increasing scarcity of water for agricultural production around the world is a major cause for concern. The situation is particularly worrying in West Asia and North Africa (WANA) where the per capita share of water in many countries has fallen below the water poverty level. With the rapid growth of the population and the consequent rise in demand for water, water shortages will be an even greater concern in the coming years. The food security of the poorer countries that depend

Table 7.1. Water requirements and water availability for the Gezira and Managil main canals (million m^3/day).

Period	Water requirement	Period	Water requirement
June I	5.81	Dec I	19.78
June II	9.27	Dec II	18.36
June III	19.13	Dec III	20.29
Jul I	23.04	Jan I	21.49
Jul II	22.41	Jan II	21.58
Jul III	15.9	Jan III	21.19
Aug I	10.67	Feb I	19.13
Aug II	12.48	Feb II	17.77
Aug III	19.8	Feb III	16.17
Sept I	27.23	Mar I	14.21
Sept II	31.66	Mar II	9.88
Sept III	34.08	Mar III	5.83
Oct I	34.59	Apr I	1.87
Oct II	33.11	Apr II	1.91
Oct III	30.03	Apr III	1.96
Nov I	31.59	May I	1.97
Nov II	30.78	May II	2.00
Nov III	29.66	May III	2.04

Note: I: First week; II: Second week; III: Third week.

largely on agriculture will be particularly threatened. In Sudan, studies revealed that the available water is not used efficiently for agricultural production and that large volumes of it are lost every year. This calls for immediate actions to mitigate the effects of water scarcity through improving water use efficiency.

The objectives of this study are to describe and characterize the satellite site and to identify the potential for and constraints to improvement of irrigation efficiency. The goal is to raise the awareness of farmers and make recommendations for better water use.

7.2 Methodology

A rapid rural appraisal (RRA) was conducted by visiting the selected sites, assessing the real situation, and collecting basic, relevant information related to the project. Based on the RRA results, and considering the objectives of the project, a questionnaire was designed for data collection. The questionnaire included all the variables needed to investigate water use efficiency and its impact on the sustainability of the water resources. Frequent meetings were held with farmers' groups to discuss issues related to the WUA and any associated problems. Data collected by a pre-testing survey was used to define the variation of the target population and to determine the sample size for the formal survey. A multi-stage, stratified, random sampling technique was used. Stratification of sampling is based on participation in the WUA. The sample size was chosen to reflect the population, the variability within the population, and the objective of the study. The questionnaire was pre-tested at the selected sites. The pre-testing survey consisted of 15 farmers in the selected villages. Two blocks, Abdelhakam and El Medina, were selected. About 93 farmers were chosen from the 670 farmers in the Abdelhakam block compared with 99 farmers from the neighboring block (El Medina), which consists of 768 farmers. Three groups of farmers were selected according to the farm location – farm distance from the irrigation canal (head, middle, and tail). Training of enumerators to complete the structured questionnaire and collect the required information to assess the impact of water use on crop productivity was undertaken. A formal survey was conducted to collect the relevant data regarding water use, farmers' knowledge about, attitudes towards, and practices governing the efficient use of water. The objective was to raise their awareness, assess the actual water productivity for multi-cropping systems, and determine the sources of inefficiency in water use in targeted areas.

The study showed that the performance of the WUAs is still very weak and needs to be strengthened, although some of them have succeeded in enforcing adequate and equitable water distribution.

The study showed that farmers' field schools (FFSs) increased the awareness of the farmers who participated in these schools (about 38%). The FFSs provided them with information regarding the adoption of new technology (25%), crop water requirements (68%), and the optimum use of inputs (8%).

The study showed that about 35% of the farmers claimed an insufficiency of irrigation water and about 49% are effectively involved in the WUA. About 32% of them participated in the field days and became acquainted with information on when to irrigate crops and on the number of irrigations to apply. About 82% of the farmers recognized that the WUAs tackle the problem of de-silting the canal, while 73.1% of them think that these WUAs will take care of the problem of the even distribution of water among users. The problem of water charges affecting the availability of water for the various crops was cited by 65% of the farmers. Only 11% of the farmers sampled pay the water charge immediately after harvest and 5% pay the water charges in installments. The introduction of subject matter specialist encouraged 7% of the farmers to pay and 27% of the cases were solved through the court. Again, about 59% of the sampled farmers cited that the WUA is a better than the previous system for irrigation.

The study revealed that about 16% of the sampled farmers are not committed to water regulations. This has a tremendous effect on the availability of water. It also revealed that only 16% of the farmers participated in the training courses regarding the operation and maintenance of field canals.

The study revealed that the awareness of farmers about the number of irrigation, operation and maintenance is high. Between 43% and 60% of the farmers responded that the amount of water applied is less than that required for irrigation.

The study showed that the water shortage has affected the farmers' behavior and led to an expansion of the sorghum areas in summer and delayed the sowing dates of the rotational crops. In this respect, about 74% of the farmers mentioned that the creation of the WUA has led to improved availability of water at the right time and in the right quantities, water management, water charges, conservation of the irrigation infrastructure, farmers' knowledge, attitudes, and practices, and a reduction in crop sharing and the sub-letting of land.

The study enumerated some advantages of the WUA as seen by the officials. These included a lifting of some of the financial burden of O&M costs from the government's budget, a reduction in overhead costs, and enhancement of the farmers' willingness to pay the irrigation fees, which is expected to lead to an improved O&M budget. the WUA also make expenditure more responsive to priority needs, they respond more promptly to O&M needs than bureaucrats, they promote a spirit of collective responsibility and the need for cooperation, and they encourage farmers to better look after the system and operate it in a more sustainable manner.

7.3 Summary of results

The study showed that water productivity was highest for cotton (0.91 kg/m^3) and lowest for other rotational crops, which include wheat (0.30 kg/m^3), sorghum (0.27 kg/m^3), and groundnut (0.26 kg/m^3). Therefore, the water yielded more output in cotton production compared to other crops. This result demonstrates the low ratios of water productivity in crop production, suggesting a tendency for farmers to over-irrigate their crops. In contrast, the gross return per unit of water was high for these crops and followed much the same decreasing pattern.

The study identified the reasons for the low irrigation efficiency. These are associated with poor timing and lack of uniformity of water applications, and leaving parts of the field over- or under-irrigated relative to crop needs. It also revealed that the operators of the irrigation systems faced many difficulties in providing farmers with a timely and reliable delivery of water that would be optimal for on-farm water efficiency.

The study concluded that water productivity in crop production is low, implying the tendency of farmers to over-irrigate their crops. Water yielded more output in cotton production than in other crops; each additional cubic meter of water yielded 0.9 kg of cotton, whereas the output of other crops was much lower. However, the gross return per unit of water was high for these crops and following much the same decreasing pattern.

When the farmers took responsibility for the minor canals, the maintenance levels appeared to vary from one item to another, with the greatest concentration being on silt clearance. This may be mainly because they are running behind the capacity of the canals and not be related to distribution efficiency. As a result, the equity of water distribution was not appreciably applied and the tertiary canals were opened randomly. This has resulted in an approximate 25% shortage of irrigation water in some areas and a 65% over-supply in others.

7.4 Recommendations

- To enhance the equity of water distribution, the minor canals must be rehabilitated. The required amount of water must be available at the proper time at the off-take point and the technical work must be under the supervision of the technical staff/ consultant.
- A good plan should be developed to open the tertiary canals in a systematic way and the operation of intermediate regulator gates must be controlled by one operator, or by a body responsible for the performance of the whole canal.
- Maintenance should consider the performance of the whole minor canal system and not focus on silt removal alone.
- The performances of the WUAs need to be strengthened to ensure adequate and equitable water distribution.
- Complementary research should take place to adapt the technical packages for improving water productivity to the selected sites.
- Agronomic recommendations that increase crop productivity and conserve soil and water resources need to be formulated.
- Workshops involving anticipated partners are really needed to raise the farmers' awareness of water and economic water use, and identify intervention options that will assist farmers to increase both their production and their family income through a more efficient use of the water resources.

Chapter 8: Measurement and sources of technical efficiency of on-farm water use in the Sudan's Gezira scheme

Chapter 8: Measurement and sources of technical efficiency of on-farm water use in the Sudan's Gezira scheme

A. El Amin, K. Shideed, M. Abdelwahab and S. Farouk

8.1 Introduction

The literature identifies two common approaches for estimating technical efficiency. One approach is based on non-parametric, non-stochastic, linear programming. This suffers from the criticism that it does not take into account the possible influence of measurement error and other noise in the data (Coelli, 1995). The second approach uses econometrics to estimate a stochastic frontier function, and to estimate the inefficiency component of the error term. The disadvantage of this approach is that it imposes an explicit and possibly restrictive functional form on the technology. However, this approach is chosen here because it permits estimation of the determinants of the inefficiency of the producing unit, which is the focus of this study.

Farrell (1957) suggested a deterministic method of measuring the technical efficiency of a firm in an industry by estimating a frontier production function. Several extensions of Farrell's model have been made. The most recent have been the stochastic frontier models developed by Meeusen and van den Broeck (1977). Stochastic frontier models were also used extensively (Coelli, 1995).

The stochastic frontier model assumes an error term with two additive components – an asymmetric component, which accounts for pure random factors (υi) and a one-sided component, which captures the effects of inefficiency relative to the stochastic frontier (u_i).The random factor (υ) is independently and identically distributed with N (0, υ) while the technical inefficiency effect, (u) is often assumed to have a half normal distribution |N (0, υ)|. The model is expressed as:

$$Y_i = x_i\,\beta + (\upsilon_i - u_i) \qquad (1)$$

$$TE_i = z_i\,\delta$$

Where xi is the vector of input quantities of the ith firm and z is the vector of firm-specific factors determining the inefficiency. The β and δ are unknown parameters to be estimated together with the variance parameters expressed as $\sigma^2 = \sigma_\upsilon^{\,2} + \sigma_u^{\,2}$ and $\gamma = \sigma_u^{\,2}/(\sigma_v^{\,2} + \sigma_u^{\,2})$. The parameter, x, has a value between zero and one such that the value of zero is associated with the traditional response function, for which the non-negative random variable, u_i, is absent from the model.

Technical efficiency is defined as $TE_i = \exp(-u_i)$. It is predicted using the conditional expectation of TE_i = exp(-ui), given the composed error term in equation (1). In this specification, the parameters, β, σ, σu, and γi can be estimated by the maximum likelihood method, using the computer program, FRONTIER Version 4.1 (Coelli, 1996). This computer program also computes estimates of efficiency.

8.2 Methodology

To assess the efficiency of on-farm water use, a fixed allocatable input model was used to estimate each model's parameters using the ordinary least squares procedure. Data used in this study are obtained from a survey in the Abdelhakam and El Medina blocks of the central group of the Gezira scheme conducted in 2007. The study area is one of the most productive areas of the Gezira scheme.

The cross-sectional data for the sample of 193 household is used to estimate a Cobb-Douglas stochastic production frontier 4. A single equation model is justified since input allocations and outputs are observed, implying the general input allocation case where technological relationships can be estimated directly without explicit assumptions that restrict either behavior or technology (Just et al., 1983). (See Chapter 7 for a description of the sampling method.)

A stochastic frontier production function was used to examine the economic efficiency and the determinants of inefficiency in the use of irrigation water in the Gezira scheme. The WP production function for the selected crops consists of the dependant variable – WP – and two sets of variables that represent the technical efficiency variables and others responsible for inefficiencies. The technical efficiency variables include quantitative variables, such as the cultivated area in feddan; product price in SDG/kg, labor used in man-days/feddan, and the cost of inputs, such as water, fertilizers, and seed in SDG/feddan. (SDG – Sudanese pound.) The inefficiency variables include qualitative factors that affect water management, such as land tenure (owned, rented, or shared), and the location of the farm from the distribution points (head, middle, tail). Also included as inefficiency variables were the farmers' perceptions, such as their participation in farmers' field schools (FFS), participation in WUAs, their awareness of the right time to irrigate crops, their awareness of when to stop irrigation, their perceptions on crop water requirements, water availability to the farm in relation to crop requirements, similarity of water at the head and tail of the canal, effective membership in WUAs, participation in field days, method of determining the quantity of water demanded, and the quantitative variable, the total number of irrigations. It is worth noting that some of the qualitative variables have more than one dummy variable. The number of dummy variables depends on the number of factors attributed to the variable in question. These variables were subjected to many iterations of the frontier production model to select the most appropriate factors responsible for technical efficiency and the sources of inefficiency. Variables in the frontier production function are as follows:

Y is the water productivity (output/quantity of water applied)

Efficiency variables

X_1 is the product price (SDG/kg)

X_2 is the water cost (SDG/feddan)

X_3 is the fertilizer cost (SDG/feddan)

X_4 is the amount of labor used (man-days/feddan)

X_5 is the seed cost (SDG/feddan)

Inefficiency variables

X_6 is the participation in FFS (participate = 1, otherwise = 0)

X_7 is the participation in WUA (participate = 1, otherwise = 0)

X_8 island tenure (owned = 1, otherwise = 0)

X_9 is awareness about the right time of irrigating the crop (aware = 1, otherwise = 0)

X_{10} is awareness about when to stop irrigation (when the water covers two-thirds of the ridge = 1, otherwise = 0)

X_{11} is the farmer perception on crop water requirement (as required = 1, otherwise = 0)

X_{12} is the location of the farm (head = 1, otherwise = 0)

X_{13} is the degree of similarity of water at the head and tail of the canal (similar = 1, otherwise = 0)

X_{14} is membership in a WUA (member = 1, otherwise = 0)

X_{15} is participation in field days (participated = 1, otherwise = 0)

X_{16} is farmer perception of the contribution of the WUA to efficient use of irrigation water (apparent contribution = 1, has no contribution = 0)

X_{17} is the determination of the demanded quantity of water (the farmer = 1, the selected farmer or field inspector = 0)

X_{18} is the total number of irrigations

8.3 Results and discussion

As mentioned before, a stochastic frontier production function was used to examine the economic efficiency and identify the determinants of inefficiency in the use of irrigation water in the Gezira scheme. The WP production function for the selected crops consists of the dependant variable, the WP, and two sets of independent variables that represent the technical efficiency variables and the variables responsible for inefficiencies. When the amount of water required for the crops was compared with the actual amount used, it was found that there was over-irrigation for all crops in the study area. For the summer crops, farm water use efficiency (FWUE) for sorghum ranged between 0.516 and 0.997, with an average of 0.83, while for groundnut it ranged between 0.498 and 0.99, with an average of 0.83. For the winter wheat crop, FWUE ranged between 0.86 and 0.988, with an average of 0.96. These estimates indicate that farmers over-irrigated sorghum and groundnut by 17% and wheat by 4% (Table 8.1). Therefore, when rationalizing the use of scarce water for the summer crops, it is possible to save an enormous amount, which can be used to expand the sorghum and groundnut growing areas, and thus increase total production. Alternatively other crops could be produced. The farmers can increase crop yields considerably under current levels of water use and with improved water and crop management practices. Either option can contribute significantly to food security in Sudan. The estimates of FWUE for sorghum and groundnut indicate a wide technological gap between the required practices and actual water application. Therefore, improving the water use efficiency for these crops can contribute greatly to overall water use efficiency in the study area and offers a high potential for saving water. These results are consistent with the findings of a recent FAO study, which concluded that water productivity seems to be lowest in water scarce regions of agriculturally based economies (FAO, 2002).

Table 8.1. Farm water use efficiency for the main food crops in the Gezira scheme.

Crop	Minimum	Maximum	Average
Sorghum	0.516	0.997	0.83
Groundnut	0.498	0.99	0.83
Wheat	0.86	0.99	0.96

The maximum likelihood estimates for the parameters in the stochastic frontier model are presented in Tables 8.2, 8.3, and 8.4. In respect of product prices, the results indicated that wheat and groundnut prices have significant positive effects on WP. This means that the prices of these crops respond positively to WP. This is normal because an increase in the product price will be expected to result in an increase in yield and consequently an increase in the WP. In this case, water consumption might be increased and that may cause an increase in the price of irrigation water which then reduce water consumption again.

Since water prices in the study area were highly subsidized, they did not have a major quantitative impact on water allocations. Previous studies showed that water demand is inelastic at low price changes (Ahmed, 2002). Because water prices are very low in Sudan, only high increases in water charges can reduce the amount of water used for irrigation, which in turn will greatly reduce the farmers' income. As expected, water costs for sorghum, groundnut, and wheat have statistically positive coefficients of about 0.08, 0.12, and 0.34, respectively. The estimates of

Table 8.2. Maximum likelihood estimates of the Cobb-Douglas stochastic production frontier function for sorghum.

Variable	Coefficient	Estimate	t-ratio
Intercept	β_0	7.60	16.8
Price of sorghum (SDG/kg)	β_1	-4.53	1.4
Water cost (SDG/feddan)	β_2	0.08	3.9
Fertilizer cost (SDG/feddan)	β_3	-0.01	27.3
Labor used (man-days/feddan)	β_4	0.03	1.5
Seed cost (SDG/feddan)	β_5	-0.003	24.1
Intercept	δ_0	1.65	22.4
Participation in FFS	δ_1	-0.016	44.0
Participation in WUA	δ_2	-0.008	22.1
Awareness about the right time of irrigating the crop	δ_3	0.068	1.2
Awareness about when to stop irrigation	δ_4	0.063	1.2
Awareness about when to stop irrigation	δ_5	0.059	1.7
Farmer perception on crop water requirement	δ_6	-0.041	1.1
Who determine the demanded quantity of water	δ_7	0.064	1.6
Total number of irrigations	δ_8	-0.992	18.5
Sigma-squared		0.006	2.6
Gamma		90.8	152.0

the individual coefficients of the water constraint suggest that an increase in water availability is allocated most heavily to crops with relatively higher requirements, like groundnut, rather than to crops with relatively low water requirements, such as sorghum. For this reason, sorghum responds to increased water costs better than groundnut. In this regard, improvements in water management have the potential to optimize water use at the farm level. Thus, sound extension strategies will be needed to increase the farmers' awareness to optimize water use at the farm level. This, in turn, will reduce the adverse effects of salinization and water logging – problems which are caused by over-irrigation – on the productivity of the land. Thus, by achieving optimal water use, it is possible to increase crop productivity in the study area, while, at the same time, ensuring the sustainable use of resources, both water and land.

The elasticity of the farm size is estimated at -0.002 for wheat, indicating that expansion in this winter crop will negatively affect the available amount of water. For groundnut, the situation may be slightly different because the crop is considered a summer crop, which receives appreciable amounts of water during the rainy season. It is worth noting that the farm size reduces inefficiency, as indicated by the positive and significant coefficient for cultivated land (0.032). This may be due to the low level of resources and technology that allow efficient operation. While the coefficient for crop establishment labor is statistically significant, the coefficients for fertilizer and seed costs for sorghum are negative, but significantly different from zero, with coefficients of -0.0079 and -0.032. This unexpected result may be associated with the water regime.

For the inefficiency variables, participation in FFS, participation in WUA, farmers'

Table 8.3. Maximum likelihood estimates of the Cobb-Douglas stochastic production frontier function for groundnut.

Variable	Coefficient	Estimate	t-ratio
Intercept	β_0	6.070	7.40
Price of groundnut (SDG/kg)	β_1	0.580	1.14
Water cost (SDG/feddan)	β_2	0.115	1.88
Area of groundnut area (feddan)	β_3	0.032	1.62
Seed cost (SDG/feddan)	β_4	0.018	25.0
Labor used (man-days/feddan)	β_5	0.063	86.1
Intercept	δ_0	-1.00	-63.8
Participation in FFS	δ_1	0.078	82.4
Participation in WUA	δ_2	0.312	2.19
Land tenure	δ_3	-1.290	90.3
Awareness about the right time of irrigating the crop	δ_4	-0.122	91.7
Awareness about when to stop irrigation	δ_5	-0.056	56.9
Farmer perception on crop water requirement	δ_6	-0.125	1.19
Location of the farm	δ_7	-0.335	-2.13
Similarity of water at the head and tail of the canal	δ_8	-0.011	-0.098
Membership in WUA	δ_9	-0.251	2.09
Participation in field days	δ_0	-0.137	-1.28
Farmer perception on the contribution of WUA to efficient use of irrigation water	δ_{11}	-0.158	-1.49
Who determine the demanded quantity of water	δ_{12}	-0.211	-1.79
Total number of irrigations	δ_{13}	-0.294	-95.6
Sigma- squared		0.069	24.9
Gamma		98.6	107.0

perceptions of crop water requirements, and the total number of irrigations are the main sources of technical inefficiency for the sorghum crop with coefficients of -0.016, -0.008, -0.041, and -0.99, respectively. Thus, a policy to increase farmers' awareness is expected to reduce the inefficiencies associated with increasing farmers' awareness of irrigation management. For groundnut, the results indicated that the proximity of the farm to the water point or minor canal, farmer's supervision to manage water distribution, and the total number of irrigations are the main sources of inefficiency with coefficients of -0.34, -0.21, and -0.29. In addition to these variables, the farmers' awareness of the right time for irrigation, when to stop irrigation, and the farmers' perceptions of crop water requirements, and effective membership in the WUA are the main sources of inefficiency with coefficients of -0.12, -0.056, -0.12, and -0.25, respectively.

Some researchers argue that tenancy management, such as share-cropping, results in an inefficient allocation of resources as well as reduced incentives to improve agricultural lands (Ahmed, 2002). The coefficients for the land contract (cultivating own land) is statistically significant and different from zero. This indicates that

Table 8.4. Maximum likelihood estimates of the Cobb-Douglas stochastic production frontier function for wheat.

Variable	Coefficient	Estimate	t-ratio
Intercept	β_0	6.13	6.31
Wheat area (feddan)	β_1	-0.002	-0.15
Labor used (man-days/feddan)	β_2	0.059	0.87
Water cost (SDG/feddan)	β_3	0.335	1.59
Wheat price (SDG/kg)	β_4	0.780	1.90
Intercept	δ_0	0.004	1.45
Participation in FFS	δ_1	0.015	0.33
Participation in WUA	δ_2	0.023	0.61
Land tenure	δ_3	-0.125	0.65
Awareness about the right time of irrigating the crop	δ_4	-0.030	-0.58
Awareness about when to stop irrigation	δ_5	0.028	0.44
Awareness about when to stop irrigation	δ_6	-0.123	-1.30
Farmer perception on crop water requirement	δ_7	0.028	0.39
Farmer perception on crop water requirement	δ_8	-0.340	-0.58
Description of water available to the farm in relation to crop requirement	δ_9	-0.029	-0.39
Location of the farm	δ_{10}	0.029	0.36
Location of the farm	δ_{11}	-0.109	-1.02
Similarity of water at the head and tail of the canal	δ_{12}	-0.028	-0.37
Membership in WUA	δ_{13}	-0.037	-0.72
Participation in field days	δ14	0.042	0.07
Who determine the demanded quantity of water	δ_{15}	0.006	0.12
The total number of irrigations	δ_{16}	-0.280	-1.24
Sigma-squared		0.009	5.54
Gamma		0.622	6.79

the levels of inefficiency associated with share-cropping and the different levels of inefficiency associated with the land tenure system can be explained by the restrictions involved and the interaction between labor and the input markets. It is worth noting that share-cropping involves a commitment by both partners to share the costs of inputs and the benefits of outputs, but places considerable restrictions on the rights of the share-cropper. Moreover, the share-cropper is responsible for providing the labor input to perform the field operations and, thus, is responsible for any sub-optimal use of labor. Therefore, despite the contribution of the landowner, in terms of inputs, lack of autonomy on the part of the share-cropper in this partnership explains the inefficiency of share-cropping. The econometric result indicates that land transactions, such as share-cropping, that involved restrictions on the farmers' decision-making are technically inefficient compared to owner-cultivated tenure. Finally, farmers who are trained are more efficient than those who received no training in improving the technical inefficiency of their farming. This result is consistent with the theory of adoption of innovation, as training and increased awareness on the farmer's part enhance technology uptake and perhaps the returns associated with the adoption.

One can conclude that product price, water prices, farm size, labor used, and inputs used are the major factors that have significant influence on the technical efficiency of irrigation water. Farmers' awareness of optimal water use at the farm level, participation in FFSs, effective participation in a WUA, location of the farm, and the land tenure system (cultivating one's own land) are the main factors that have significant influence on technical inefficiency for the cultivated crops in the Gezira scheme. Thus, a policy to increase farmers' awareness is expected to reduce the inefficiencies associated with the irrigation management. The study concluded that policies create most of the conditions that determine the levels of water use efficiency, such as farm size, water allocation and costs, cropping patterns, input subsidies, and crop prices. In this respect, policy setting is really needed in the crop areas and crop-mix, given an increasing trend towards free market prices that create conflicts in resource use between the national and farm levels resulting from conflicting objectives. The study recommends conducting research programs to develop varieties with low consumptive water use coupled with agronomic recommendations that increase crop productivity and conserve soil and water resources. A variety of research areas will need to be considered in the light of the policy and institutional constraints. These include the monitoring of economically optimum crop water requirements that maximize returns on irrigation water under changing conditions of commodity prices and adoption of free-market policies, efficient water pricing systems, institutional aspects of water distribution among users, and regulations regarding irrigation water use.

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Annex: Project dissemination and potential uptake

Annex

Project dissemination and potential uptake

The objective of the project was the widespread integration and adoption of proper irrigation management technologies for increasing water productivity in a sustainable farming system by the communities in the irrigated areas. Listed below are many of the dissemination and capacity building activities which were undertaken.

- The main stakeholder groups which were targeted were:
- At the community level, farmers under various irrigation conditions (old lands, irrigational lands, and new lands)
- Water users associations
- Extension agents
- Government and non-government organizations; Ministry of Agriculture and Ministry of Water Resources and Irrigation (MWRI).
- Agricultural research organizations
- Project groups, IFAD, World Bank, CARE, and others
- Donors, IFAD, Arab Fund for Economic and Social Development (AFSED), and the Organization of Petroleum Exporting Countries (OPEC).

1. Dissemination venues

The project adopted the community participatory approach. This approach provides a better way of responding to the farmers' needs by involving local communities in the planning, implementation, monitoring, and assessment of the various project activities. Also, this approach better facilitates the dissemination of the project interventions to the community members directly or indirectly through the spill-over effect. This is why the irrigation benchmark (IB) project emphasizes the use of the community participatory approach as its course of action. Various stakeholders participated in the different steps of the activities from preparing the work plan through implementation, to monitoring the project activities.

1.1 Linkages with development projects and policy makers

The IB project developed strong links with other relevant projects and institutes. This helped very much in disseminating the interventions developed in the project for increasing water use efficiency (WUE).

These projects included:

East Delta new lands agricultural services project

The East Delta project is funded jointly by IFAD and the World Bank. The project links included:

- An exchange of visits by the farmers, graduates, extension, and technical team from the project to the old lands site. These visits took place during the summer of 2006 and the winters of 2006-2007 and 2007-2008. During the visits the East Delta visitors talked with the IB farming communities about the benefits of the interventions used to save water, the costs, the increasing yield, and WUE. The IB team visited the East Delta project area and exchanged information with the farmers of the area. Also, the raised seed bed method of growing crops was demonstrated for wheat and faba bean during the winter and for rice and cotton during the summer. The East Delta project used those sites as learning classes for the farmers of the areas and the various stakeholders.

- Through the IB project, activities and interventions are being introduced and exchanged in the newly reclaimed areas of the project. This contributed to better management of the land and water resources in East Delta. The East Delta project is being implemented on about 200,000 feddans of new area.

Link with Middle Egypt crop intensification project

- This covers three governorates of Middle Egypt, Fayom (cultivated area 433,571 feddans), Beni Saif (cultivated area 293,300 acre), and El-Menia (cultivated area 484,667 acre).
- The IB team made several visits to the project area and delivered several presentations about the IB concept and achievements. Key agricultural leaders, extension staff, and other stakeholders participated in these activities. As a result, the Middle Egypt crop intensification project adopted the IB interventions and made raised seed bed demonstration fields in the three governorates for wheat, faba bean, cotton, and maize. The improvement in WUE was evident and the link with the project is being expanded to scale up the IB developed technology to the Middle Egypt governorates.
- Other links were established to projects managed by the MWRI, through the Irrigation Improvement sector. The IB findings were presented to the MWRI, Irrigation Improvement sector during 2005-2006. Additionally, the IB team made several presentations to key agriculture teams in Behaira and Sharkia governorates where the cultivated areas are about 849,030 acre and 791,734 acre. Also, there were exchanges of visits to the IB old lands site for farmers' leaders of the area, extension agencies, and water irrigation engineers. As a result, the IB technology is being accepted by those projects in these governorates, for the major crops, as it saved on water and costs, and increased yields. These joint efforts need to be intensified to disseminate the IB technology to all the farming communities.
- Links were established with the national improvement programs for major field crops.
- The IB technology for field crops was disseminated in the major governorates.

Communication and links with policy makers

The IB project was very keen to involve policy makers at various levels from the beginning and throughout its various activities. Policy makers reached included:

- President of the Agricultural Research Council (ARC)
- Directors of the Field Crops Research Institute (FCRI)
- Directors of relevant ARC institutes – Soil and Water, Agricultural Economics, and Agricultural Extension and Rural Development
- Heads of various research sectors in ARC.
- MWRI
- Water users associations.
- Under Secretary for Extension
- The Under Secretary for Agriculture in various governorates – Monifia, Behira, Dakahlia, Sharkia, Beni Suef, Fayoum, and Menia.
- Various media facilities – radio, newspapers, etc.
- Various policy-makers at various levels attended workshops, presentations, field days, and key project activities.

Workshops and meetings

The project organized several workshops and meetings at various levels with various stakeholders and committees at the selected project sites. A project initiation workshop was held in January 2004, which was attended by more than 150 people. These included policy-makers, research committees, extension staff, leading farmers, and private-sector and water users associations. The project held regular monthly meetings at each site, to discuss work in progress. Also, the project communities, at various levels, held monthly meetings to monitor and follow-up on the progress of the work.

Training

Farmers' field schools (FFS), field days, and harvest days

As a result of those activities, the project-developed interventions were better disseminated throughout the farming communities. Within the last two seasons the raised bed method has spread to between 5% and 10% of the area under the major field crops.

Farmer training

Farmer training was achieved through FFS, field days and harvest days.

Farmers' field schools

The IB project is of great importance as far as its activities and expected outputs for maximizing water productivity through various tested interventions are concerned. The FFS approach is a good tool for disseminating the results of the various interventions and for educating farmers to become experts in adequate water management. The training was based on comparison studies with the water treatments applied by the farmers throughout the crop season.

Approach and concepts of water management

The need for sustainable agriculture production through well water management is very urgent in the new lands, where the sandy soil is very low in its water holding capacity and macro and micronutrients. It is also urgent in the old lands, where the farmers used to apply excess water and chemical fertilizer, and in the marginal lands where unequal water distribution and a lack of crop diversity exist. To overcome these problems FFS were established in those areas. The FFS were held twice each month and about 25 farmers participated in each.

Timetable of activities at the FFS

The different activities conducted at the FFS schools are summarized in Table A.1. They illustrate the activities undertaken at the different stages of crop development during the growing season.

Field days

Visits for on-farm trials

About six field days were carried out for the benefit of farmers from other governorates visiting the on-farm trial sites throughout the growing season. The participants also included extension engineers from the Ministry of Agriculture and irrigation engineers from MWRI. In those field days, the participants talked with the farmers of the IB sites about how growing crops on raised seed beds saved irrigation water, increased fertilizer efficiency, and increased yields, as well as the various aspects of crop management.

Harvest days

At harvest times, farmers, researchers, and extension teams participated in the estimation of the yield. It was found that wide furrows saved water and recorded higher water productivity while reducing irrigation costs.

Publications

Extension bulletins, with support from the faba bean and wheat programs (FCRI). Two bulletins were produced on the

Table A.1. Farmers' field schools for better water management conducted twice monthly during the 2005-2006 and 2007-2008 seasons.

Month	Location	Topic	Objective
January	Monofia	Hold FFS to explain water interventions, weed control, and fertilizer use. Visit of Dr Benli to Monofia. Suggest conducting clover experiments.	To teach farmers proper irrigation treatments, weed control to prevent yield loss due to weed competition, and precise use of fertilizer to minimize environmental pollution.
February		Apply Granstar® and Tropik® to control broad leaf weeds and wild oats.	To show farmers how to select and use herbicides correctly to control weeds.
March		Evaluate the effects of water interventions.	To know the benefits of and differences among various water treatments
April		Field day for researchers, extension agents, and farmers at wheat sites.	To transfer the technology developed to the farmers.
May		Visit of an ICARDA mission to evaluate the impact of water interventions on the wheat harvest.	To demonstrate to the farmers the impact of different irrigation interventions.
		Train farmers to grow maize.	To learn the farmers' methods of weed control, fertilizer use, and irrigation practices for maize.
June		Harvest wheat.	To show the farmers the effect of irrigation interventions on wheat.
July		Discuss the winter's results. Examine the farmers' attitudes to the water treatments.	To make farmers familiar with the benefits of the water treatments.
August		Visit of researchers from the maize program, extension staff, and farmers.	To study the effect of irrigation treatments on maize.
		Field day for farmers visiting from the Behera irrigation project to show the achievements of the benchmarks project.	To transfer the technology developed in the project to extension staff and farmers of El Behera governorate.
September		Harvest maize.	To share in the farmers' harvest.
		Harvest maize.	To share in the farmers' harvest.
		Cotton picking.	To share in the farmers' harvest.
October		Cotton picking.	To share in the farmers' harvest.
		Start sowing of the wheat and clover trials.	To conduct irrigation treatments for clover.
November		Discus raised bed and deficit irrigation interventions.	To familiarize farmers with the work being carried out.
December		Explain weed and fertilizer management in relation to the project treatments.	To make farmers aware of the best crop management practices.
January	El-Serw	Visit of Dr Benli to El-Serw to meet farmers.	To follow- up benchmarks project.
February		Discus effects of treatments and water management in relation to minimizing chemical fertilizer levels.	To inform farmers of the effects of irrigation interventions on wheat and the relationships with fertilizer use efficiency.
March		Field trip and FFS.	To evaluate effect of interventions on wheat growth.
April		Harvest wheat	To compare the yields of different irrigation intervention

Table A.1. seasons continued.

Month	Location	Topic	Objective
April	El-Serw	Harvest wheat	To compare the yields of different irrigation intervention
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		Harvest wheat	To compare the yields of different irrigation intervention
May		Dr EL Gualley and ICARDA mission meet and have discussions with farmers.	To evaluate the achievements of ICARDA and the benchmark project activities.
June		Discussion between farmers and researchers about growing rice and cotton in the projects.	To teach farmers recommended irrigation, weed control, and fertilizer treatments for rice and cotton crops.
July		Discus the results of the treatments on rice growth.	To evaluate the effect of the interventions on rice and cotton growth.
August		Visit partners of FFS field trial and discus and comment on the effect of the interventions.	To develop farmers' capabilities to evaluate effects of the treatments.
September		Pre-harvest of rice and cotton	
October		Meet with and explain to extension workers and farmers the improved irrigation scheme.	To transfer the benchmarks project technology developed to farmers of at the improved irrigation scheme in Behera.
November		Sow wheat and clover.	To prepare land for planting for wheat (5 sites) and clover (1 site) trials.
December		Explain about better chemical fertilizer management.	To reduce inputs cost and increase net return to farmers.
January	Bustan	Apply Granstar® and Tropik® against weeds. Explain macro and micro nutrients deficiency (deliver sheets for fertilizer use). Apply water requirements according to the schedule. Deliver sheets for irrigation schedule and quantities.	To deliver catalog of mineral deficiency symptoms to farmers. To train farmers to identify weeds in wheat fields and to control them with recommended herbicides.
February		Explain critical growth periods of crops for irrigation. Estimate the efficacy of herbicides for controlling weeds.	To deliver and explain the sheet on the critical periods for irrigation.
March		Irrigation during March.	To focus on night irrigation and increase water requirement by 15%.
April		Harvest faba bean. Harvest wheat.	To estimate the yields from different water interventions.
May		Water, weed and fertilizer management in peanut.	To inform farmers on peanut management and water interventions for this crop.
June		Evaluate weed control treatments for peanut.	To explain to farmers the importance of controlling weeds by Fusillade® or complementary hand weeding to avoid weed competition.

Table A.1. seasons continued.

Month	Location	Topic	Objective
July	Bustan	Evaluate water interventions. Determine farmers' perceptions of treatments.	To make farmers aware of new technologies and their benefits.
August		Inspect for nematode infection in peanut.	To make farmers aware with nematode injury and methods of management.
		Evaluate water irrigation interventions on growth of peanut.	To transfer the technology to peanut cropping.
September		Prepare for harvest	
		Harvest peanut at all sites	To make farmers aware of the effects of different irrigation interventions.
October		Explain the project activities to farmers. Problems of irrigation. distribution systems. Identify water and fertilizer problems. Sowing wheat and faba bean for trials.	To manage FFS through the season. To improve water management in the new lands. To put in place the system for solving water distribution problems. To help solve water and fertilizer problems Prepare for planting wheat and faba bean trials.
November		Estimate sprinkler and drip irrigation discharges. Practical training on estimating required NPK depending on soil analysis.	To deliver instruction sheets for conducting water distribution tests and precisely applying recommended water requirements. Deliver sheet about soil analysis and required NPK to farmers.
December		Practical training on delivering water requirements for wheat and faba bean during December and January. Train farmers to identify weeds using a weed catalog.	To provide sheets to train farmers to estimate the amount of water to be added. To provide farmers with a weed catalog to assist in identity weed species for control Purposes.

production of faba bean and wheat in which planting on wide furrows is explained and recommended for faba bean and wheat growers nation-wide for the first time. This was based on the recommendations of the IB project.

Articles published in newspapers popularizing the IB project's achievements; five in El-Ahram, three in El-Ahram Economic weekly magazine, two in El-Taawon, and one in Watny. The IB technology was explained to policy-makers and farming communities.

Reports were provided to the ARC Administration for briefing H.E. the Minister of Agriculture.

Capacity building

Extension training, lead farmers' training, farmers' training

Training on the project activities was conducted at various levels.

Staff training – several training workshops were organized for agricultural and irrigation engineers. In these courses, the project team focused on issues related to increased water use efficiency

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Equipment – a raised bed machine is being ordered for the project. The project supplied about six computers and some water measuring facilities. Also, office supplies and working facilities were supplied.

1.2 Uptake of the project's yearly outputs

The project team extended the project approach to other projects, such as CARE's agriculture and natural resources program, IFAD's East Delta project, IFAD's Middle Egypt project, and the World Bank's improvement projects in Sharkia and Behaira governorates (Ministry of Irrigation).

The project was successful in bringing together scientists from various national institutes and agencies to plan and implement various project activities. The scientists were from the Ministry of Agriculture, MWRI, various research institutes, non-government organizations, such as WUAs, and agricultural cooperation organizations. All this facilitated uptake of the project technologies developed and the approaches to be adopted for various similar activities carried out by other agencies

Regional collaborations

Two regional meetings, attended by the project's donors, were held in Cairo, the first in January 2004 and the second in January 2007.

The satellite site in Sudan, in collaboration with the Egyptian IB project is considering adopting the approaches and interventions developed. Also, the interventions developed are being considered for adoption in similar irrigation schemes in other WANA countries.

Adoption of the technologies

The technologies developed address increasing water productivity under scarce water conditions. This was achieved in close collaboration with the communities in the target areas.

The technologies developed included:

- Growing major field crops on raised seed beds instead of the conventional methods of basin irrigation or narrow furrows
- Dry planting of berseem clover instead of the wet planting method
- Growing berseem in raised seed beds
- Proper irrigation management under drip and sprinkler irrigation systems in the new land areas.

In general, the new methods developed by the project show that:

- The IB project, using the community participatory approach, has developed several interventions which help to better manage irrigation water, land, and crops for increased water use efficiency.

The raised-seed bed developed for growing major field crops, replaces the conventional basin irrigation methods, increases yield as well as saving about 25% of the irrigation water applied by the farmers. Also, farmers' incomes have increased by 15% and the net return per unit of water used, by 20%.

- Farmers' perceptions of the technologies developed were very positive and showed wide acceptance since they are easy to adopt. In addition they provide many other benefits to the farmers, mainly in the forms of increased productivity as well as WUE.
- The project's approaches were also followed during the last two seasons by CARE in Fayoum, Sohag, and Quna governorates in Upper Egypt, in that field visits to the project sites and farmer training were carried out in addition to demonstrating the raised seed bed method for wheat and maize.
- The feed-back from farmers indicated that water savings were of the order of 30% and the yield increased by about 20%. The savings on nitrogen fertilizer were between 30% and 40%. All these savings resulted from better management of the irrigation water which reduced fertilizer losses. The same trend was found in Sharkia, Behaira, Dekahlia, and Menofia governorates. These encouraging results led to the adoption, by the Ministry of Agriculture, of the project findings during the 2008-2009 season. The ministry recommended the use of the raised bed seed method nationwide; it was to be used by the extension staff in their demonstrations to farmers. The methodology and approaches developed by the project are unique in terms of the involvement of the farming community, which speeded up matters by shortening the time needed for technology development. In two years, the raised seed bed method for major crops was included in the ARC's extension bulletins distributed to farmers. The normal time for farmers to recognize a new agronomic practice can be from 5 to 7 years. Likewise, as a result of the cooperation on the water improvement projects, the methods were adopted by the farmers through the WUAs.

Influence of government investment on the new initiatives

As a result of the project findings, the ARC will invest in a raised seed bed machine to facilitate adoption of the IB developed technologies. Also, other projects in Egypt are considering using the project methodology, especially projects associated with the Ministry of Agriculture and the MWRI.

Framers' travelling workshops

To exchange experiences and encourage more interactions among farmers, travelling workshops by teams of scientists and extension workers were held (six times a year). The travelling workshops were very effective in getting feed-back from the participants. This was reflected in the project activities, like developing the raised seed bed and broadcasting to suit all farm sizes.

1.3 Potential uptake

The three selected sites of the project represented the old lands (70% of the Delta area), the marginal lands where low quality water is used (30% of the cultivated land area in Egypt is salt-affected to different degrees), and the new lands, representing about 1 million acres of sandy soil suffering from poor fertility. Therefore, the project-developed technologies for saving water had a wide impact on agricultural production. Through active interaction with farming communities and links with various projects and stakeholders, the project-developed technologies achieved wide acceptance. As a result, within the last two seasons, between 5% and 10% of the area devoted to the major field crops is adopting the new technologies. Indeed, this year during the national meeting for winter crops, comprising the top ARC scientists and extension staff, the raised seed bed method of growing crops was given a high priority for dissemination as the preferred method for growing major field crops.

It is evident that this project-developed intervention is being embedded in the national system of extension. Moreover, the concept and approaches are being taken up by various projects through the project team. In general, the project activities have been extremely successful. They have become the accepted technology for sustainable water management under scarce water conditions and for increased water productivity. Moreover, all this is being reflected in improvement of the farmers' livelihoods.

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For further information visit:
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