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

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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).

Farm	Soil fertility analysis			Physical and chemical analysis					
	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

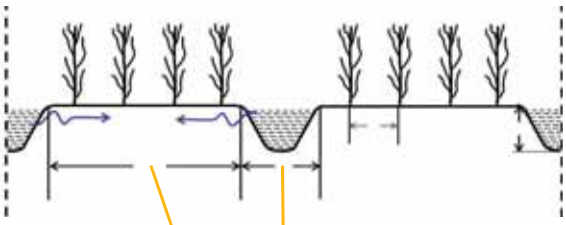

Figure 1.2. Schematic diagram of the raised bed method of wheat production.

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.

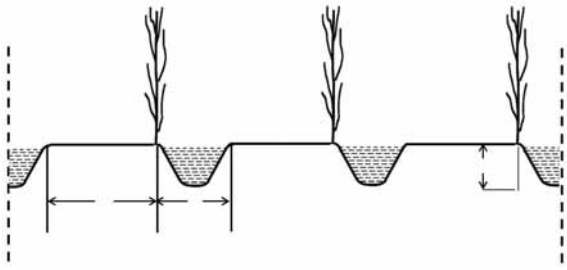

Figure 1.4. Schematic diagram of the traditional furrow method.

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.

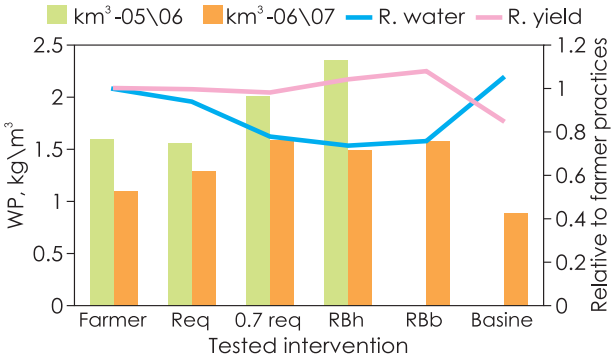

Figure 1.7. Average and relative amounts of water applied, wheat yield, and WP in the old lands during the 2005-2006 and 2006-2007 seasons.

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/m³)	Full requirement (kg/m³)	0.7 full requirement (kg/m³)
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/m^3)					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/m^3 (26%) and 0.509 kg/m^3 (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/m^3 (4.4%) and 0.568 kg/m^3 (37.7%) during the 2006 season and from 0.237 kg/m^3 (22%) and 0.688 kg/m^3 (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/m^3)	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.