Paper 2 – Draft

“WP-Calc” for exploring some water productivity improvement scenarios

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1. Introduction

The aim of this study is to investigate some scenarios aiming to improve water productivity of the level of mesqa irrigation zone at the traditional irrigated agriculture in the Nile Delta region. “WP-Calc” will be used for exploring the impact of the investigated scenarios on the water productivity of the mesqas.

2. Materials and methods

2.1 Description of the case study

A case study was conducted in order to provide the “WP-Calc”, under the conditions of traditional irrigated agriculture in the Nile Delta region, at the winter and summer seasons of 2011/2012. Actual data were collected from a pilot location in Behaira Governorate, to be represent the actual current conditions of the irrigated agriculture in old land (Figure1). The water source of the location is originally from El Nasery Canal then Sabya and Habib tertiary canals. The location has only one main drain of Nasr Allah drain. The study total area is 596 Feddan, with 201 and 410 Feddan in Sabia and Habib respectively. The studied command area had eleven Mesqas, the command area, and the total water supplied by each Mesqa for agricultural seasons of 2011/2012, are listed in in table (1).

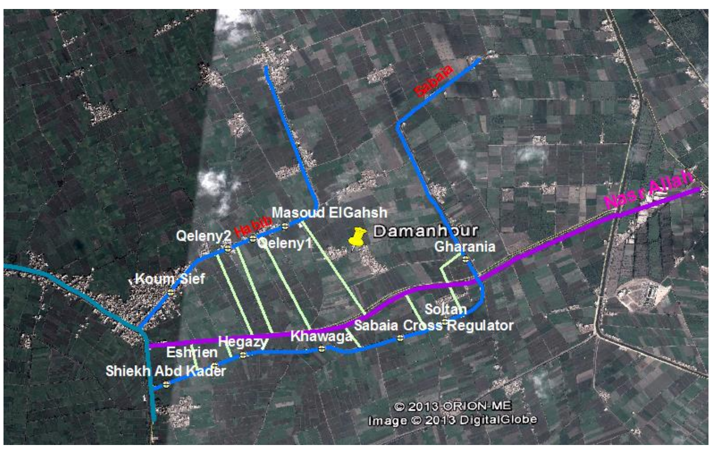


Figure (1): The location of the evaluation case study (at Behaira Governorate)

Table (1) The command area and the total water supplied by each Mesqa at the study area (agricultural seasons of 2011/2012).

canal	Mesqa	Command area (Fed)	Total water supplied (m^3/year)
Habib	Kom Sief	85	743920
	El Keleny 2	45	433170
	El Keleny 1	59	418192
	Masoud El Gahesh	77	569107
	El Shiekh Abd El kader	50	417550

	El Eshreen	85	704905
Sabaia	Heqazy	35	425635
	El Khawaga	45	365040
	Soltan	35	285110
	El Gharania	40	372240
	Soliman	40	288080

2.2 Crops

The dominated crop pattern at the command area of the case study had rice and cotton as the major crops at the summer, remaining small areas of maize and vegetables. While, wheat and barseem (short clover) was the major dominated crops at the winter season, with very small areas for vegetables. The WP-Calc simulations is including wheat, barseem, cotton, rice and maize crops. Tables (2) listed the planting and harvesting dates of the five crops in the study area. Table (3) shows the average values of the actual crop yields from some pilot fields at each mesqa of the case study, which were used to evaluate the crop response simulation. Whereas, table (4) presents the guidelines of the national values of the studied crops water productivity (kg·m^{-3}), and the equivalent calories per kg of the primary crop yield of the studied crops.

Table (2): Planting and harvesting dates and growth duration of the studied crops

Season	Crop	Planting [month]	Harvesting [month]	Duration [days]
Winter	Wheat	11	5	180
	Clover (Barseem)	10	3	100
Summer	Cotton	3	9	180
	Rice	6	9	100
	Maize	5	8	120

Table (3): Average crop yield [ton/ ha] of the studied crops, from pilot fields at the studied mesqas.

Canal	**Mesqa**	**Yield [ton/ha]**				
		Wheat	**Barseem**	**Cotton**	**Rice**	**Maize**
Sabaia	Hegazy	5.06	80.41	2.01	9.32	5.46
	El Khawaga	5.01	75.63	2.10	9.49	5.01
	Soltan	4.51	68.31	2.45	9.23	5.50
	El Gharania	4.16	67.50	2.63	9.15	
	Soliman	5.41	78.37	2.02	9.16	5.41
	Average	**4.83**	**74.04**	**2.24**	**9.27**	**5.34**
Habib	Kom Sief	5.08	79.80	2.00	9.79	5.08
	El Keleny 2	5.04	68.23	2.99	9.02	5.54
	El Keleny 1	4.50	63.11	2.05	9.29	5.25
	Masoud El Gahesh	4.22	67.40	2.09	9.46	5.61
	El Shiekh Abd El kader	4.55	67.01	2.66	9.13	5.55
	El Eshreen	4.79	62.00	2.79	9.49	5.79
	Average	**4.70**	**67.92**	**2.43**	**9.36**	**5.47**
Average		**4.76**	**70.71**	**2.34**	**9.32**	**5.42**

Table (4): guidelines of the national values of the studied crops water productivity (kg·m^{-3}), and the equivalent calories per kg of the primary crop yield of the studied crops

	wheat	Barseem	Cotton (fibers)	Rice	Maize
WP_c [$kg \cdot m^{-3}$]	0.9-1.4	17-29	0.1-0.2	0.7-0.8	0.7-1.2
Calories per kg	3509	1080	5600	3439	3615

2.3 soil data

The average soil classes and texture of the study area are presented in table (5). Based on the classification the hydraulic properties of each layer were calculated.

Table (5): the average soil texture, classification and the average hydraulic properties of the study area

Depth [cm]	Soil Texture			Classification	PWP	FC	SAT	Sat Hydraulic conductivity [mm/day]	Matric bulk density [g/cm3]
	Clay %	Silt %	Sand %		% volume				
0-25	42	30	28	Clay	25.4	39.3	49.9	71.28	1.33
25-50	41	35	24	Clay	25	38.4	48.5	61.68	1.37
50-75	36	28	36	Clay loam	22.4	35.5	46.8	85.44	1.41
75-100	27	23	50	Sandy clay loam	17.6	29.4	44.6	209.04	1.47

2.4 Model description

“WP-Calc” is a computer modeling framework provide a numerical and spatial analysis of a given irrigation scheme, and provides an integrated analysis of water and salt balance, water productivity, irrigation efficiencies, and irrigation adequacy. It has two connected routines, one for on-farm irrigation management and another routine for irrigation distributary network. Both routines are linked together in an integrated framework, and attached with simple GIS environment. The concept and the theoretical basics of the model were described by Attaher et al. (2016) . WP-Calc utilize the FAO AquaCrop model (Steduto et al., 2009; Raes et al., 2009; Hsiao et al., 2009), as the basic modeling core of the on-farm routine, via attaching the “AquaCrop” plugin “ACsaV40.EXE” (Version 4.0) with the other modules of WP-Calc. Furthermore, it has four modules of, (i) water balance analysis module, (ii) salt balance module, (iii) water-productivity module, and (iv) irrigation efficiencies and adequacy module. The current version of WP-Calc, can perform a simulations for ten crops (wheat, cotton, rice, faba bean, sugar beet, sugar cane, potato, tomato, and vegetables).

2.5 Scenarios

In the current study, WP-Calc is used to investigate the impact of three scenarios on the water productivity at the given irrigation zone. The investigated scenarios are (i) deficit irrigation, and (ii) raised beds, and (iii) lower irrigation quality.

The deficit irrigation scenario is studying the impact of the deficit irrigation on the water productivity of the irrigation zone, for the five studied crops, considering two types of irrigation applications; (i) applying 70% of the potential irrigation applications at all crop stages (Dif70_A), and (ii) applying 70% of potintial irrigation applications for only vegetative & maturity crop stages (Dif70_B). This scenario considered the current climate conditions and future projected climate change conditions. The average amount of applied water by the “farmers” is illustrated in table (6), which also includes the average yield and WP_c of the studied crops.

Applying raised beds method is the second scenario investigated in this study. The simulations of this scenario focused on wheat, cotton and maize crops, where barseem and rice cultivation systems and irrigation management are included in the simulations as in the farmer’s usual practices. In the raised bed system, wheat seeds are planted over the ridges with the same plant density as in the farmer’s usual practices. Whereas, cotton and maize seeds were planted in wide farrows, which combining two narrow furrows together, keeping the plant density constant. 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 and soil evaporation losses.

Table (7) lists the values of partial soil surface wetted, which are used by WP-Calc as a major distinguishing parameter between the different irrigation systems. Similar to the first scenario, this one considered the current climate conditions and future projected climate change conditions.

Table (7): The partial surface wetted values [%] used in WP-Optimizer for different irrigation methods

Irrigation system	Partial soil surface wetted [%]
Basin	100
Borders	90
Farrow	50
Narrow farrows	85
Wide furrow (combining two furrows)	40
Raised beds	60

The lower irrigation quality scenario, effect of using irrigation water with increasing levels of salinity by annual accumulative values. This scenario is trying to find out the long term impact of using the drainage water as irrigation water for a given irrigation zone.

2.6 Current and future climate

A daily climatic data of two years (2011 &2012) from the nearest meteorological station in Behaira Governorate was used in the simulation. The station is located at 30.65 ºN latitude, 30.70 ºE longitude, and 16 m altitude. The data included the main climate parameters, of (i) maximum and minimum temperature [°C], (ii) maximum and minimum relative humidity [%], and (iii) precipitation [mm]

Air temperature raise (Table 8) and CO_2 response, were the climatic factors used in the simulation referring to future climate change. The Maximum and the minimum monthly values of air temperature changes of the Nile Delta region were determined from a downscaled implication of IPCC SRES scenarios using HadCM3 GCM climate model up to year 2100 (Attaher, 2009). The future ET_o values (Table 9) were determined by using FAO ET_o Calculator software (Raes, 2009). In climate change simulations, the impact of air temperature increase was assessed basically on the water balance parameters, where the impact on the crop biomass production and the harvest index is assessed by AquaCrop model.

Table (8): the projected downscaled Δ air-temp over the northern Nile Delta region, under worst and best cases of IPCC-SRES.

IPCC- SRES	**ΔT (°C)**		
	2025s	**2050s**	**2100s**
A1 [Worst case]	1.2-1.3	2.4-2.7	4.6-5.4
B1 [Best case]	1.1-1.2	1.2-1.8	2.1-2.5

Table (9): Seasonal and annual maximum (Max), minimum (Min) and average (Avrg) ET_o change rate (%) due to climate change for the Nile Delta region

	Scenario A1 [Worst case]														
	2025s					2050s					2100s				
	DJF	MAM	JJA	SON	annual	DJF	MAM	JJA	SON	annual	DJF	MAM	JJA	SON	annual
Max	8.8	5.2	3.4	3.5	3.7	12.7	8.6	7.6	7.4	7.7	18.7	14.8	14.6	13.8	14.7
Min	3.1	2.5	1.4	2.9	2.7	6.3	5.3	4.7	6.1	5.7	11.2	10.4	10.6	6.1	11

Avrg	4.6	3.4	2.7	3.2	3.1	8.4	6.7	6.2	6.7	6.6	14.3	12.9	12.2	11.4	12.5
	Scenario B1 [Best case]														
	2025s					2050s					2100s				
	DJF	MAM	JJA	SON	annual	DJF	MAM	JJA	SON	annual	DJF	MAM	JJA	SON	annual
Max	8.6	5	3.2	3.3	3.4	10.7	6.9	5.8	5.9	5.8	11.1	7.9	6.6	6.3	6.6
Min	3	2.4	1.2	2.7	2.5	4.7	3.9	3.3	4.7	4.3	5.1	4.8	4	5.1	5
Avrg	4.4	3.2	2.5	3	2.9	6.4	5	4.7	5.3	4.9	6.9	6.1	5.4	5.7	5.7

2.7 Model performance indicators

The size of the grid boxes is defined based on using the feddan as the measuring unit of the land area, therefore the cell size in this case study was 4200 m^2 [64.81m X 64.81m], with a cell depth: 0.25 m (equal to the depth of the soil profile layers). Accordingly, the grid of this case have 2940 cell.

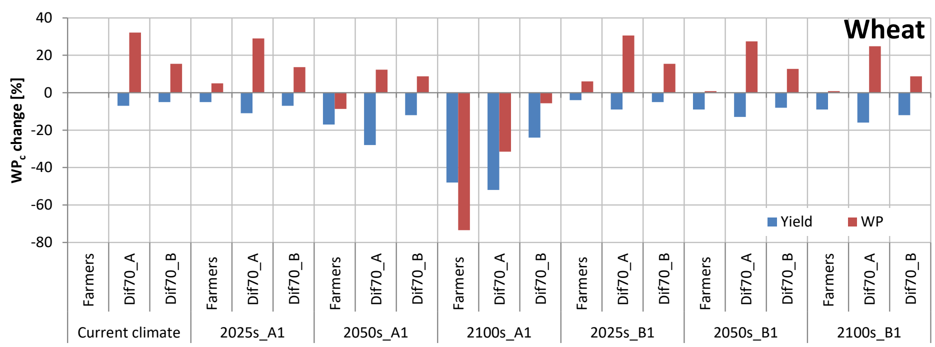
A set of performance indicators have been employed for water balance analysis of the canal system, such as water level, routine discharges and cropping patterns of tertiary canals, pump operations for mesqas, irrigation events, water salinity, drained water depths and salinity, crop yield, application adequacy, and distribution efficiency. The measured data presented the spatial and temporal water distribution pattern among the system.

3. Results and discussion

3.1 Deficit irrigation scenario:

Applying Dif70_A saved about 30% of the irrigation water, whereas Dif70_B saved about 11% of the irrigation water. Figure (2) shows the impact of applying the deficit irrigation applications on the crop yield and WP_c of the studied crops, under current and future climate conditions. Applying Dif70_B for the studied crops had a good impact on reducing the reduction of the crop yield, which normally occurs under deficit irrigation practices. Barseem revealed lowest reduction levels of crop yield, and the highest increase in WP_c, between the studied crops under the current climate conditions. However, rice had the highest values of yield reduction with lower WP_c increase under deficit irrigation applications.

Climate change is remarked to cause a reduction on the yield and WP for the majority of the agricultural crops. In the current investigation only cotton and barseem showed some increase in a crop yield under climate change conditions.



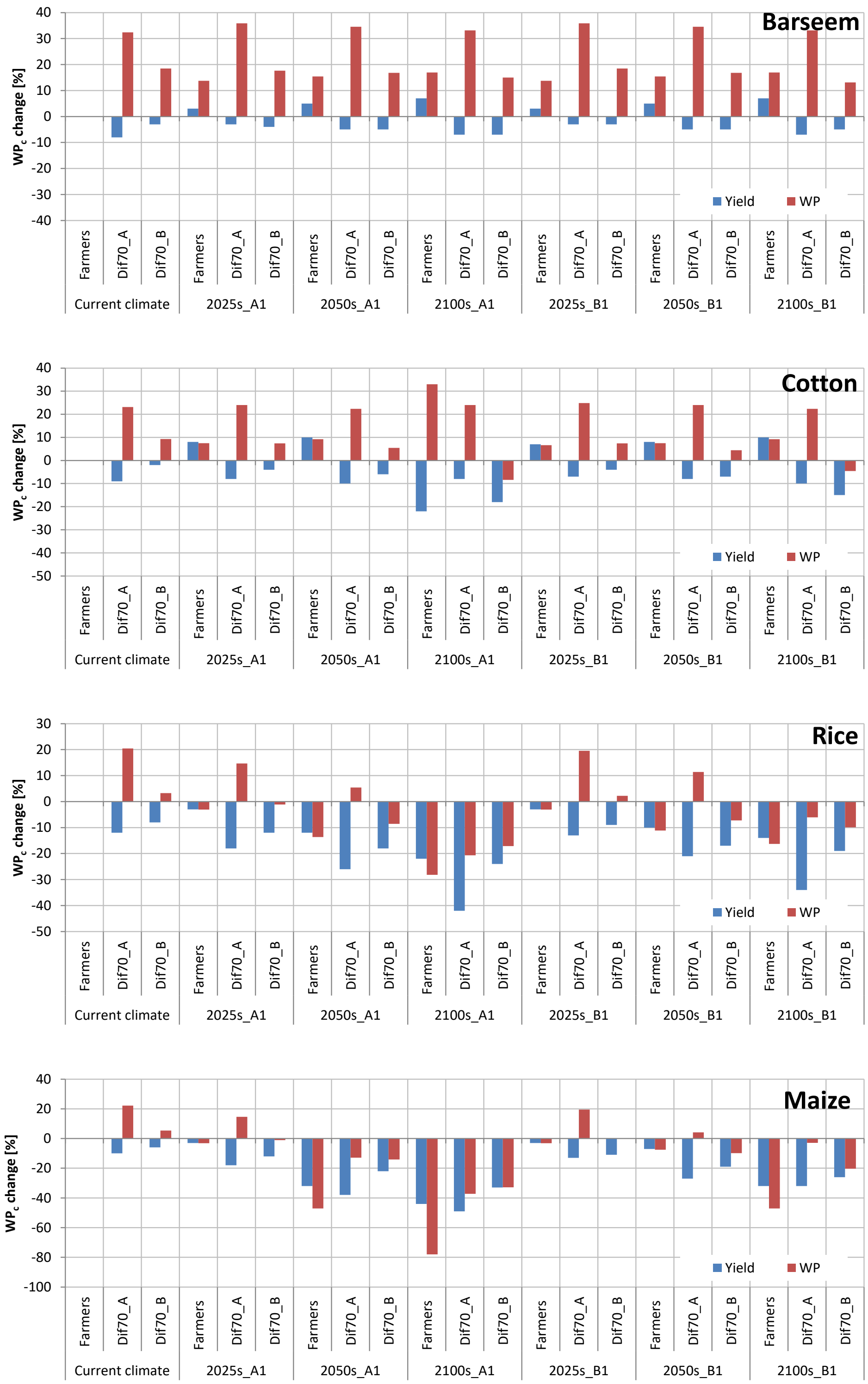


Figure (2): the impact of farmers' irrigation application vs. two types of deficit irrigation (Dif70_A and Dif70_B), on the average changes [%] in crop yield and WP_c of the studied crops, under A1 and B1 scenarios by 2025s, 2050s and 2100s.

Figure (3) shows the resulted maps of WP_m [calories $\cdot m^3$] distribution, resulted from WP-Calc simulations. The pattern of the distribution of WP_m is remaining almost the same under all treatments of the simulation.

Based on the general averages, the current irrigation applications of the farmers are reducing WP_m under all climate change conditions. In spite of both Dif70_A and Dif70_B are increasing WP_m, Dif70_B application have the potential of obtaining the balance between the reductions of the yield with an acceptable improvements in WP.

At the tertiary canals level, Dif70 indicated the highest improvements values of WP_m, with an average 6 and 12% increase for Habib and Sabaia canals, respectively.

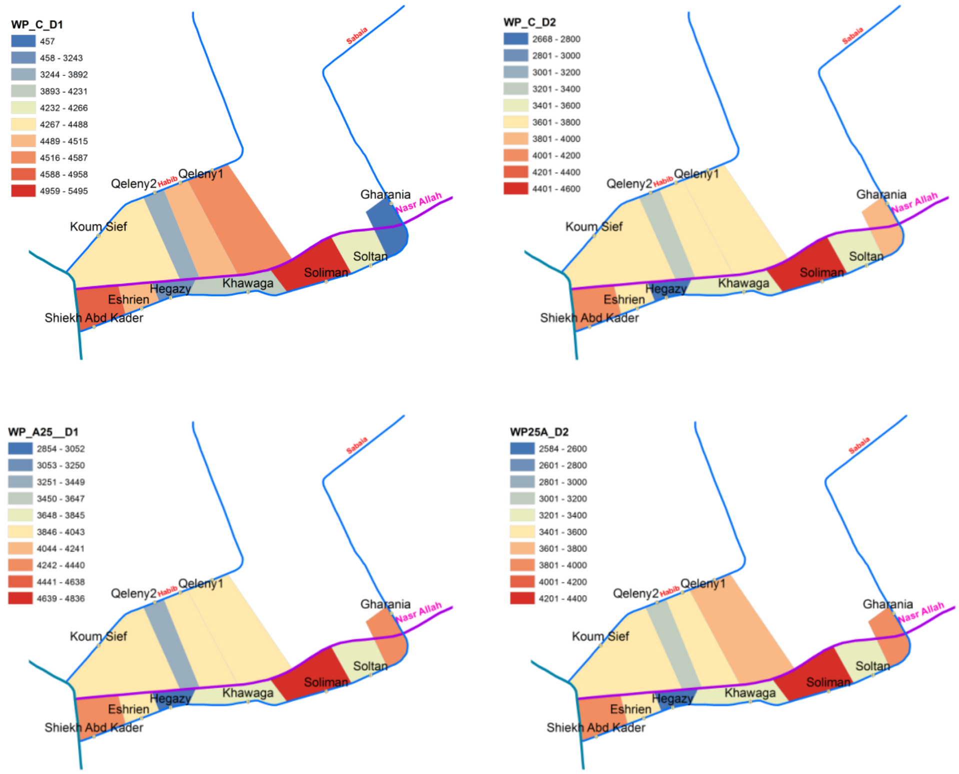
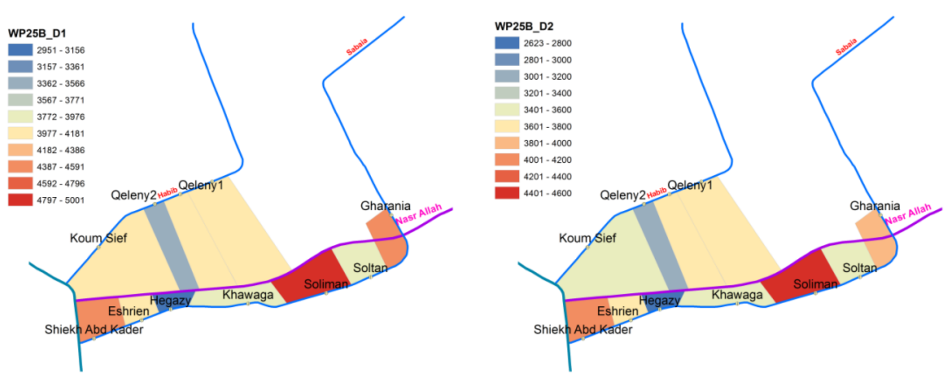


Figure (3): the impact of farmers' irrigation application vs. two types of deficit irrigation (Dif70_A and Dif70_B), on WP_m [calories $\cdot m^3$] of the studied mesqas , under A1 and B1 scenarios by 2025s, 2050s and 2100s.



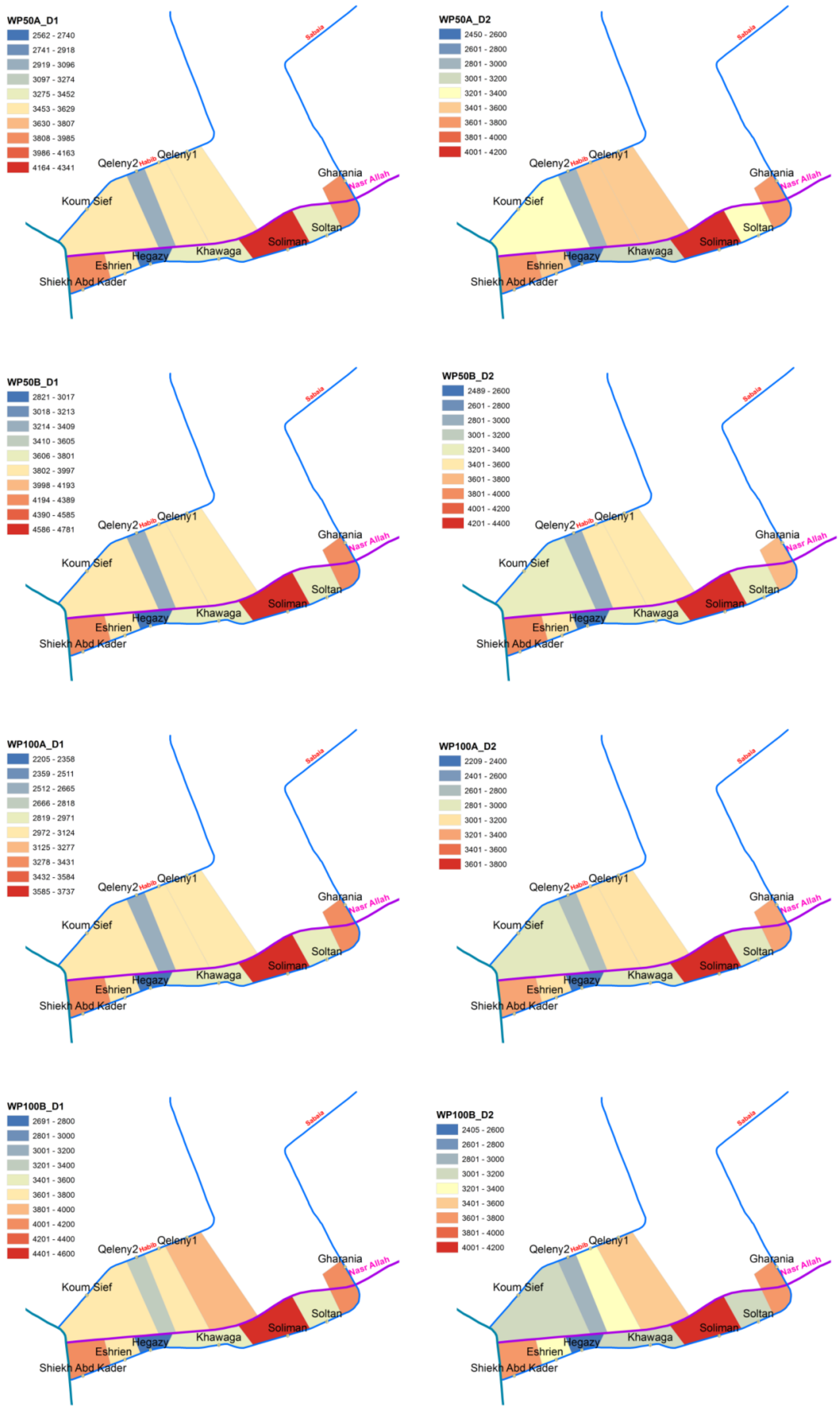


Figure (3) cont.: the impact of farmers' irrigation application vs. two types of deficit irrigation (Dif70_A and Dif70_B), on WP_m [calories $\cdot m^3$] of the studied mesqas , under A1 and B1 scenarios by 2025s, 2050s and 2100s.

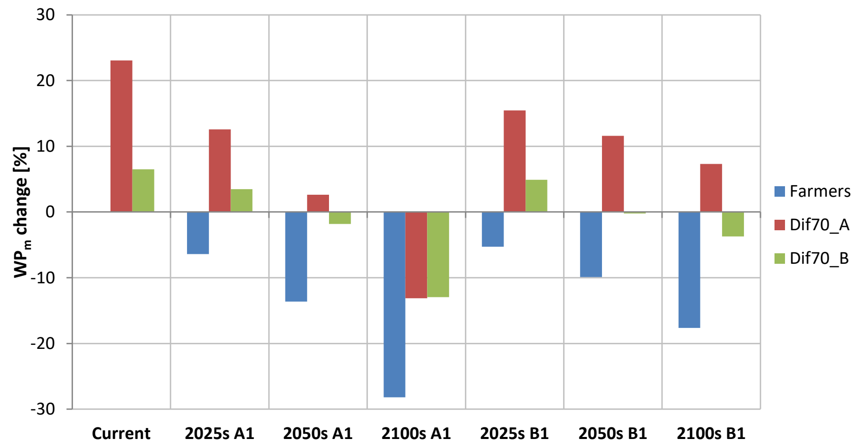


Figure (4): the impact of farmers' irrigation application vs. two types of deficit irrigation (Dif70_A and Dif70_B), on the average changes [%] in WP_m of the studied mesqas , under A1 and B1 scenarios by 2025s, 2050s and 2100s.

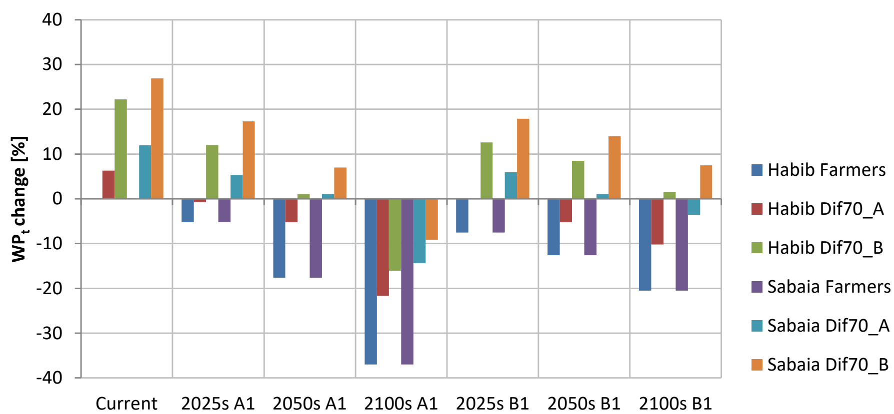


Figure (5): the impact of farmers' irrigation application vs. two types of deficit irrigation (Dif70_A and Dif70_B), on the average changes [%] in WP_t of Habib and Sabaia tertiary canals, under A1 and B1 scenarios by 2025s, 2050s and 2100s.

3.2 Raised-beds scenarios:

From the results of the simulations under the current climate conditions, raised beds have a good impact on improving the application efficiency at the farm level. The indicated average decreases in the applied water were 23 %, 18 % and 15% for wheat, cotton and maize, respectively. This reduction in irrigation application companied with an increase in yields by 22%, 8% and 9% for the same crops.

Furthermore, using raised beds technology reduced the harmful impact of climate change on the crops yield to significant levels (Figure 6). WP_c values increased by using raised beds, and the highest recorded value was determined by wheat crop (49%).

Figure (7) show the resulted maps of WP_m [calories $\cdot m^3$] distribution, resulted from WP-optimizer simulations. The pattern of the distribution of WP_m is remaining almost the same under all treatments of the simulation. Raised beds application has the potential of minimizing the reduction of the yield with significant improvements in WP (Figure 8) ,under climate change conditions.

At the tertiary canals level, raised beds indicated good improvements of $WP_{m,}$ with an average 9 and 13% increase for Habib and Sabaia canals, respectively.

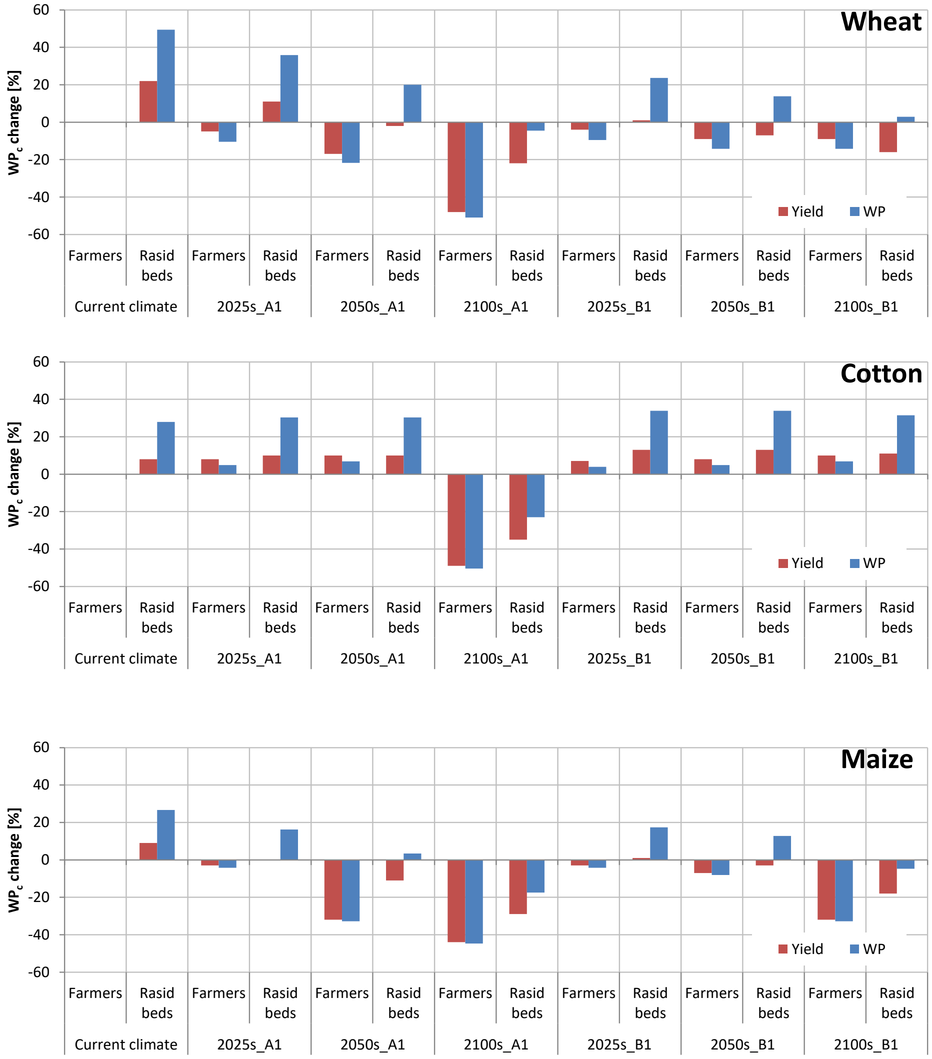
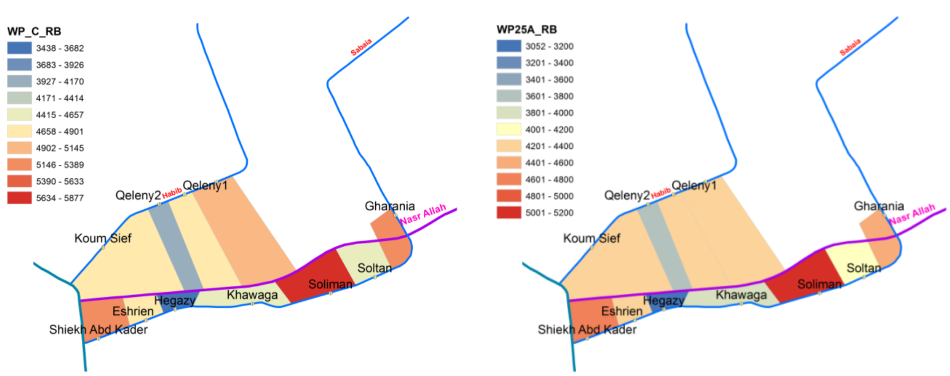


Figure (6): the impact of farmers' irrigation application vs. raised beds technology, on the average changes [%] in crop yield and WP$_c$ of the studied crops, under A1 and B1 scenarios by 2025s, 2050s and 2100s.



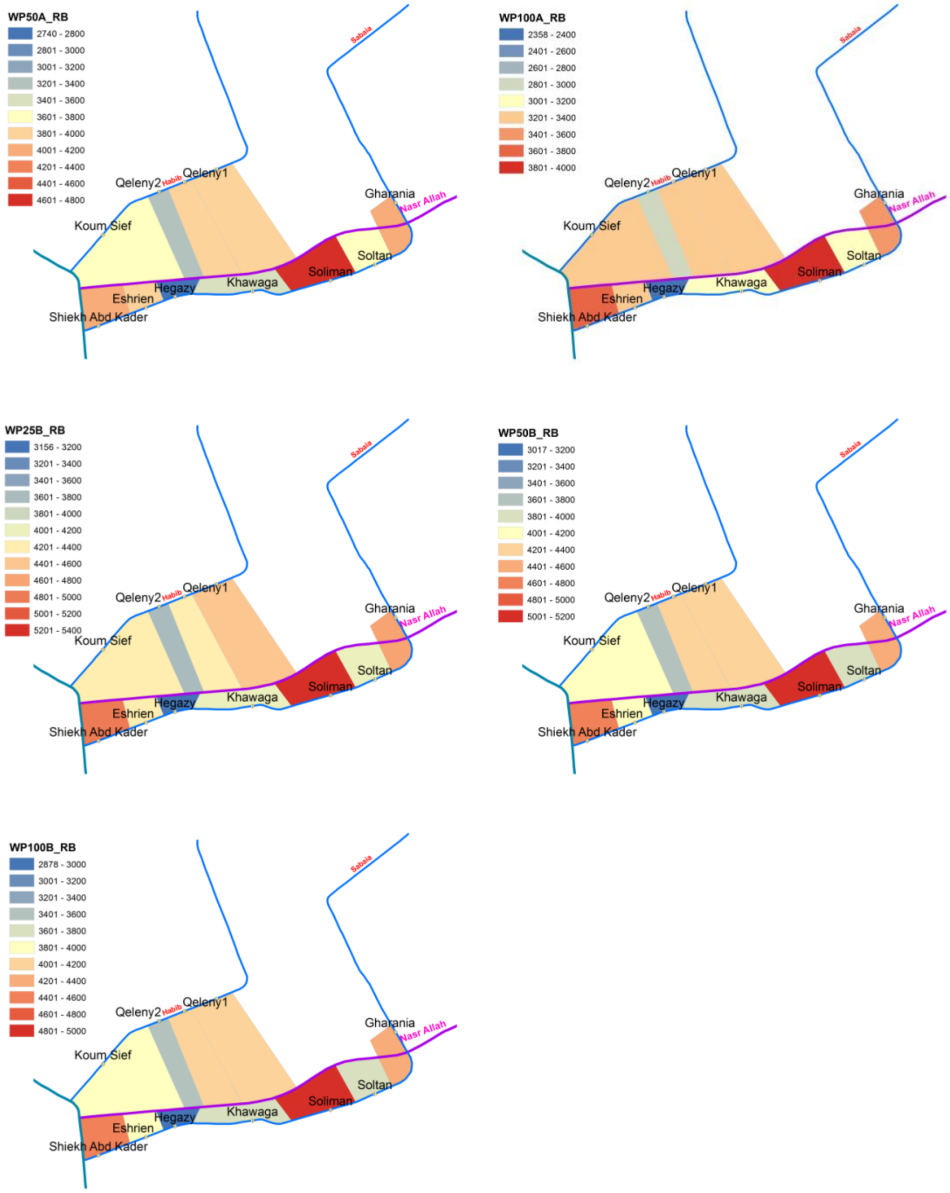


Figure (7): the impact of farmers' irrigation application vs. raised beds technology, on WP_m [calories $\cdot m^3$] of the studied mesqas , under A1 and B1 scenarios by 2025s, 2050s and 2100s.

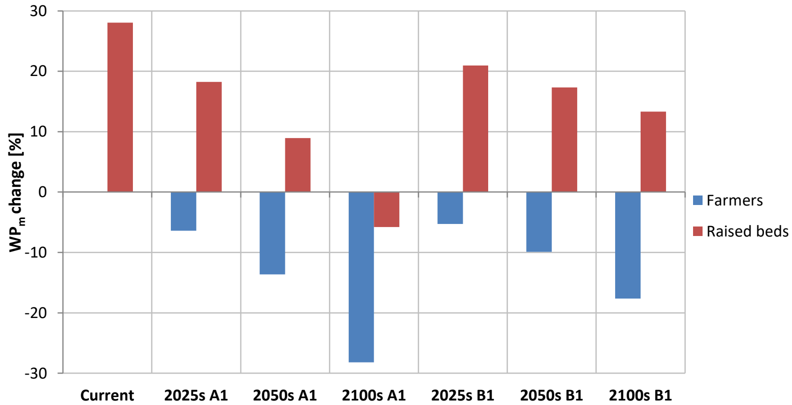


Figure (8): the impact of farmers' irrigation application vs. raised beds technology, on the average changes [%] in WP_m of the studied mesqas, under A1 and B1 scenarios by 2025s, 2050s and 2100s.

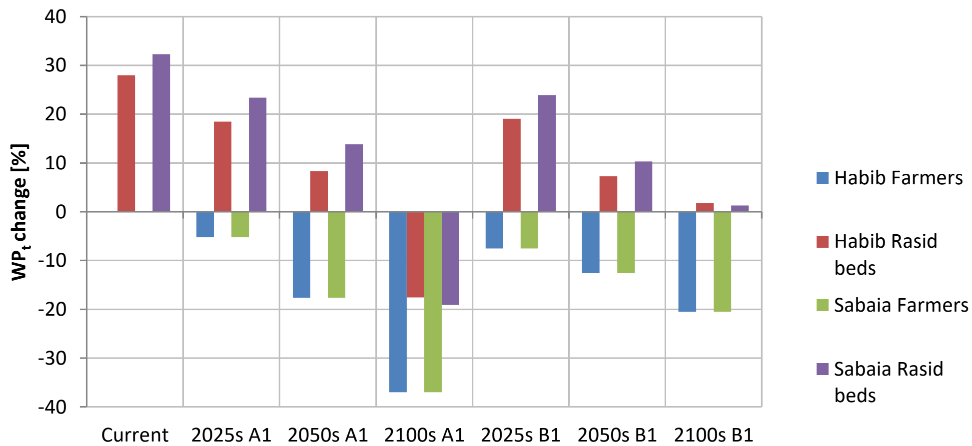
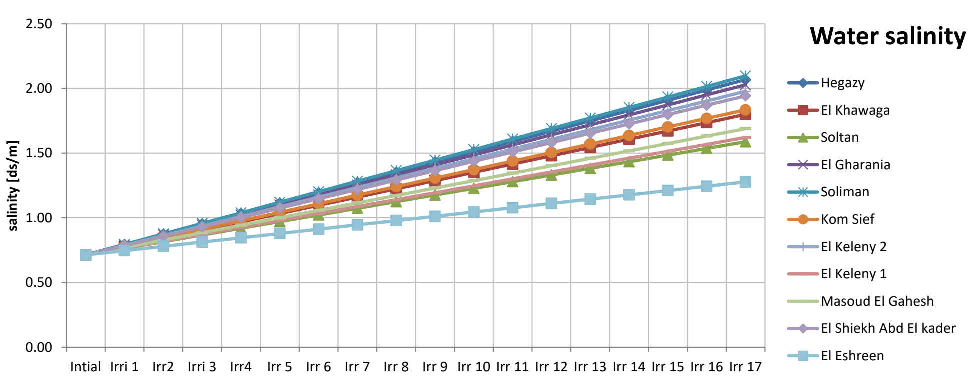


Figure (9): the impact of farmers' irrigation application vs. raised beds technology, on the average changes [%] in WP_t of Habib and Sabaia tertiary canals, under A1 and B1 scenarios by 2025s, 2050s and 2100s.

3.3 lower irrigation quality scenario



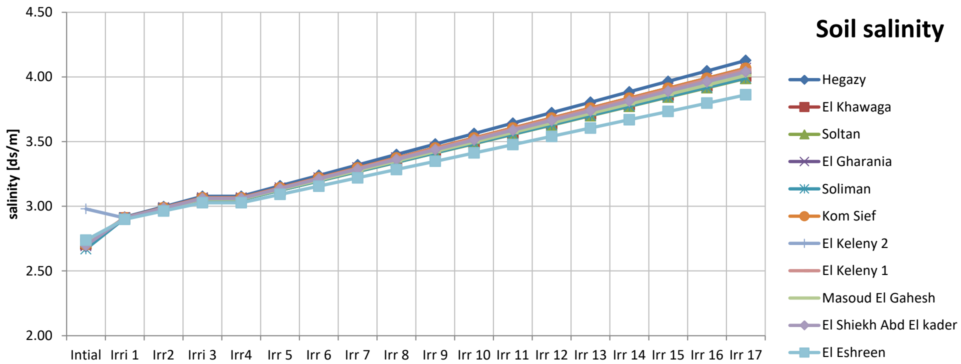


Figure ( ): the change in water and soil salinity due to the cycled application of irrigation water, simulated by WP-Calc

Figure ( ) the impact of the cycled application on water productivity

4. Conclusions

The analysis of the two investigated scenarios concluded that applying raised beds technology and deficit irrigation at some defined crop stages, could have a good impact on water productivity of the irrigated pilot zone in the Nile Delta region, and it could be considered as a climate change adaptation option to be targeted to more detailed studies.

Acknowledgements

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References