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Sustainable safe reuse of drainage water in agriculture at North delta soils, Egypt

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ABSTRACT

In rural and peri-urban areas of most developing countries, the use of sewage and wastewater for irrigation is a common practice. Wastewater is often the only source of water for irrigation in these areas. Even in areas where other water sources exist, small farmers often prefer wastewater because its high nutrient content reduces or even eliminates the need for expensive chemical fertilizers. In order to meet this projection, Field experiments were carried out in different demonstration fields at North Delta. Maize and cotton crops were cultivated in the growing season of 2014. A split-plot design was used, where main plots were assigned to the different irrigation water sources e.g. fresh water, sewage water, drainage water, drainage water alternative with fresh water and sewage water alternative with fresh. Three methods of irrigation namely; traditional surface irrigation, gated pipes and surface drip irrigation were laid in sub plots. By summarizing these results in easy readable charts, fiber crop such as cotton is preferable to be cultivated when treated waste water used in irrigation. Also, drip and gated pipe irrigation saved water in clay soil and increased irrigation application efficiency and water productivity. Alternating of low quality water with fresh water can optimize the water unit return due to saving fresh water.

Key words: Waste water, drip irrigation, gated pipes, water unit, irrigation application efficiency

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INTRODUCTION

In the whole world, demand of water has increased, while the availability of fresh water was bounded in worldwide and water scarcity affected every continent of the globe and about 700 million people in 43 countries were under water stress [World Bank, 2011].

The available sources of water cannot fulfill the increasing demand of water and hence the scarcities of water may change with the changing patterns of weather.

The scarcity of water is also deeply linked with food security. Thus, irrigation system can play an important role to food security and sustainable income, specifically in developing countries. More than 900 million people live in water shortage river basins (closed basins), while more than 700 million peoples are living in those areas, where the limit to water resources is fastly approaching. One billion people were living in those basins where economic constrained boundary the speed of more required investments in water management [Molden et al., 2007].

In Egypt water and land are the main natural resources that Egypt relies up on. As far as water concerned the River Nile supplies Egypt with about 55.5 billion cubic meter annually. The agriculture area 5% of the total area of Egypt's land. Plants do exist for increasing this area which is estimated to be slightly more than 7 million feddans (one feddan = 4200 m^2). Land does not represent at present a constraint for horizontal expansion, it is rather the water that is the critical parameter. Therefore, the Egyptian government has some programs and policies for large scale use of ground water and non conventional water resources, drainage water and treated waste water. About 9 billion cubic meter annually of agriculture drainage water is planned to be reused for irrigation.

Nile Valley and Delta soils are mainly irrigated based on surface irrigation system which is with quiet low efficiency that ranged of about 47 up to 50%. Due to limited water resources, arid climate and fast increasing of in population, more water is required for eliminating the demand available balance gape. Therefore, developing surface irrigation by using gated-pipes technique provides an important tool to improve its performance. Uniform water flow may be regulated by adjusting the size of the outlet opening manually with some difficulties, which may be reducing water application. [Osman, 2000] mentioned that good design of gated pipes with precision land -leveling may improve the water distribution uniformity and save irrigation water by about 12 and 29 % in cotton and wheat, resp. [El-Sayed, 1998] found that the required head to efficiency. Short flexible sieves may be attached to the outlets to dissipate energy and minimize erosion at furrow inlets. Operate the GP is 50 cm or less under alluvial soil conditions. [El-Gindy et al., 2000] found that by using gated pipe, irrigation significantly affected fruit shape homogeneity and specific weights of fruit and pericarp.

Water resources in Egypt are limited to the Nile River, rainfall and lash loods, deep groundwater in the deserts and Sinai, and potential desalination of sea and brackish water. Each resource has its usage limitation, whether these limitations are related to quantity, quality, space, time, or exploitation cost. Egypt receives about 98% of its fresh water resources from outside its national borders. This is considered to be the main challenge for water policy and decision makers in the country as the Nile River provides the country with more than 95% of its various water requirements.

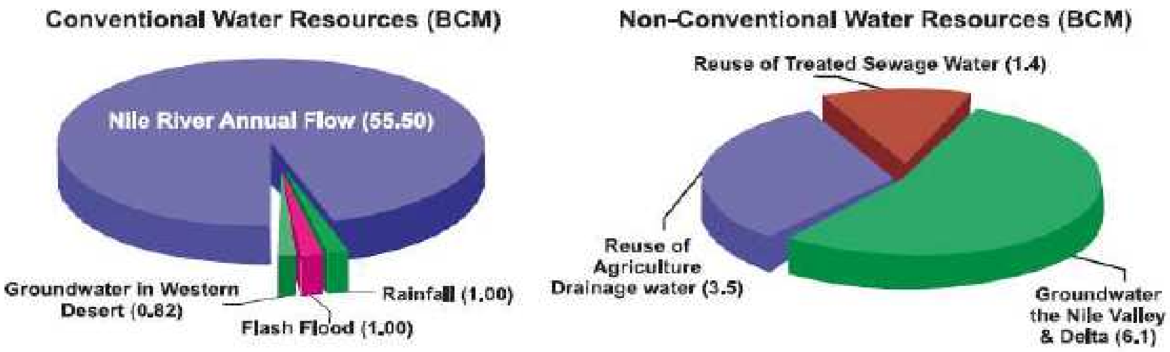

Fig.1. Water resources of Egypt

As illustrated in Figure 1, the average annual quota of Egypt from the conventional water is limited in the Nile River which is determined as 55.5 BCM according to the 1959 agreement with Sudan. Another 0.82 BCM per year is utilized from groundwater in the Western Desert, in the Nubian sandstone aquifer, which extends below the vast area of the New Valley Governorates and the region east of Owaynat. Another 1.0 BCM per year is utilized from rainfall along the coastal area and lash loods occurring within short-period heavy storms in the Red Sea area and Southern Sinai that are directly used to meet part of the water requirements or used to recharge the shallow groundwater aquifers. Desalination of seawater in Egypt has been given low priority as a water resource because the cost of treatment is high compared with other sources [Amer et al., 2005].

Desalination is actually practiced in the Red Sea coastal area to supply tourist villages and resorts with adequate domestic water supply where the economic value of the water is high enough to cover the treatment costs.

The non-conventional water resources include the renewable groundwater aquifer underlying the Nile valley and delta, the reuse of agricultural drainage water, and the reuse of treated sewage water. The amount of the groundwater in the Nile valley & delta is estimated at 6.1 BCM per year, the reuse of agriculture drainage water is about 3.5 BCM per year and the reuse of treated sewage water is about 1.4 BCM per year.

These limited quantities of water have to fulfill the Egyptian requirements in the fields of agriculture, which is the largest consumer of water (85%), industry and domestic uses. Increased population needs more water for domestic use as well as horizontal expansion to maintain the per capita of cultivated land. This reclaimed area either will increase the agriculture share of water or will reduce the quantity of water allocated per feddan (in case of fixing the agricultural share of water) which in return decrease the crops. yield. Also development of industry will consume more water which will affect the Egyptian water balance.

[Oster and Rhoades,1990] worked out a model, Watsuit, permitting to forecast with a reasonable approximation the effects of a determined kind of water on soil sodicity and salinity and therefore, within limits, also on crops.

Selecting the method of water application is important when managing saline water. It is evident that wetting leaves with sprinkling irrigation, particularly during daytime, worsens plant conditions; on the opposite the best are drip and furrow methods. With drip irrigation, it has been demonstrated long ago that salts concentrate at the periphery of the moist bulboid, which is formed in the proximity of the emitter, thus maintaining a relatively better water quality inside it. With furrow irrigation, it has been demonstrated that the best conditions for plants are obtained when a twin plant row is worked out on the ridge top since this way.

Drip irrigation system is being used in all over the world and the leading countries are France, South Africa and USA with 90, 37 and 21% area under drip, respectively. Drip irrigation system is more efficient than other methods such as surface irrigation methods. Drip irrigation system had field level application efficiencies of 70 - 90%, as losses of deep percolation and surface runoff are decreased to very low [Ashraf, 2012]. In was found that in maize crop the 75% of the roots present in top 40cm soil layer and similar for drip irrigation system [Wan and Kang, 2006; Wang et al., 2007]. Drip irrigation can maintain high soil metric potential in the roots due to its slow rate and high frequent application. Thus, reduction in osmotic potential can also be counter balance by consistence irrigation water for maintain the high crop growth. Therefore, drip irrigation has been regarded as the most advantageous method for applying irrigation water to crops. Drip irrigation system could be used for more crops per unit water to be grown and this system allows crop cultivation in those areas where water availability is very low to irrigate by surface method.

Determining the extra amount of water to be applied beyond that is required to satisfy plant needs is not a simple task; the generally suggested equation, according to which leaching requirement LR is directly proportional to EC in irrigation water and inversely proportional to EC in drainage water ($LR = EC_{irr} / EC_{drain}$) is nebulous and incomplete, since it does not specify the intervals of water application for leaching nor the real threshold value for EC in drainage water. Besides it does not explain that actually EC_{irr} value is that resulting from the weighted arithmetic average of rain water (negligible) and irrigation water EC, nor does it take into account the “leaching efficiency” of rain and leaching water.

Furthermore it can be objected that there is no reason to apply water in excess proportionally to water salinity, it is sufficient to apply just the excess water needed to drain excess salts, when the need arises**.**

This study therefore aims at demonstrate an appropriate on-farm irrigation methods and management practices for re-using marginal water for economical production of maize and cotton crops.

EXPERIMENTAL SECTION

1.1. Location

The field experiments took place during the summer growing season of 2014 in different locations at Kafr El-Sheikh governorate (North Delta) as showing in Fig.2. The first location irrigated by fresh water was close to branch from River Nile (Meet Yazeed Canal), the second location irrigated by sewage water from El-Gharbia main drain, the third location irrigated by sewage and fresh water was in El-Hamoul district, the fourth location irrigated by drainage water from drain No.7, and finally the fifth location irrigated by drainage and fresh water apart 20 Km from Kafr El-Sheikh Governorate. Five fields of approximately 800 m^2 each were rented from local farmers and fenced.

The general climatic situation in the experimental area is summarized in Table.1. The area is characterized by a typical Mediterranean climate, with a hot and dry summer season. Weather data, including daily values of air temperature and humidity, wind speed and sunshine were collected at the agro meteorological station of Sakha Agriculture Research Station.

1.2. Soil and irrigation water characteristics

Soil texture was clay in all of experimental fields. Values of soil field capacity were 39, 40,38, 41 and 42 % for locations 1,2,3,4 and 5 respectively. Also, mean values of permanent wilting point were 20,20.5,18,20 and 21%. Mean chemical analysis of different sources of irrigation water in different locations, during summer season are shown in Tables 2 and 3.

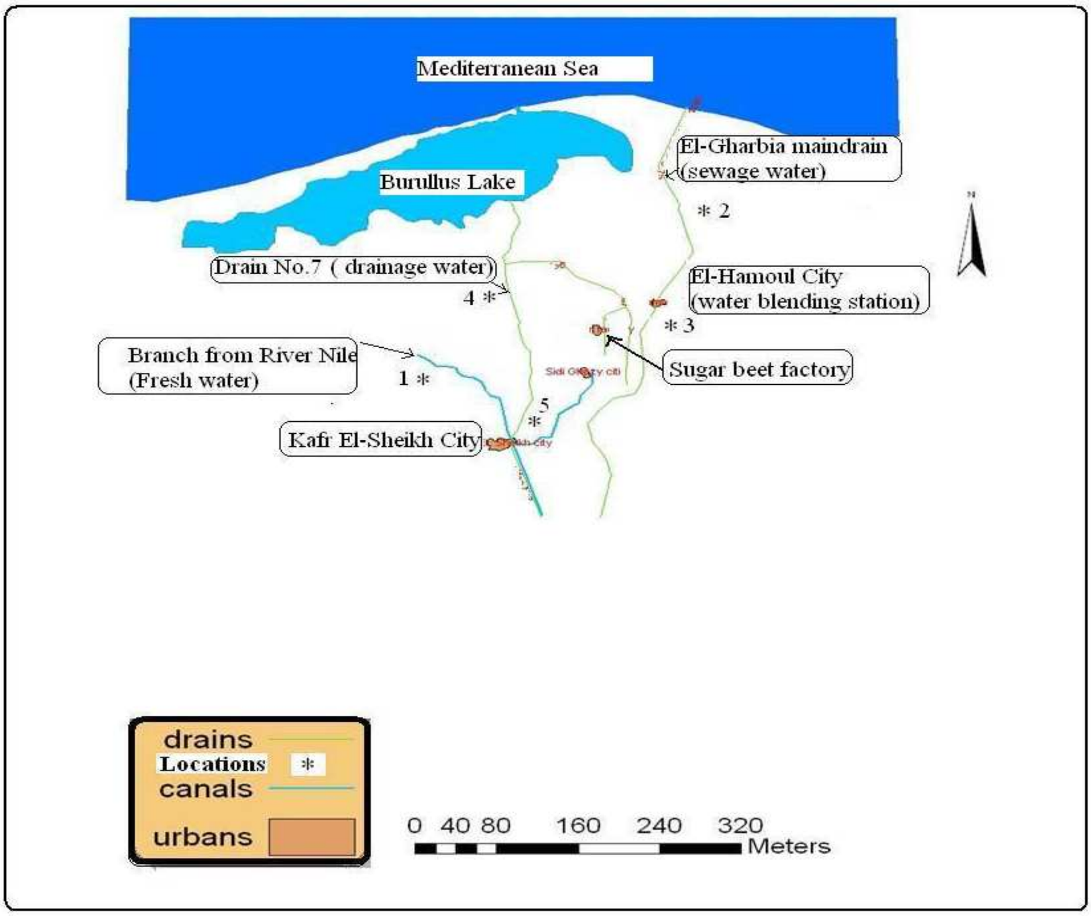

Fig.2. Location map of the experimental fields at North Delta soils, Egypt

Table 1: Meteorological data during summer growing season period 2013

Months	Mean temp. C°	Relative humidity %	Wind speed Km day^{-1}	Sunshine hours
March	22.5	65.54	250	10.2
April	24.5	60.50	248	10.5
May	25.7	61.38	240	11.0
June	29.3	68.30	207	12.5
July	29.1	71.19	180	12.3
August	28.0	69.58	170	11.5
September	25.8	66.30	175	10.4
October	24.4	60.20	180	10.0

Table 2: Mean chemical analysis of the different sources of irrigation water during summer season 2013.

Water sources	ECdSm^{-1}	SAR	COD Mg L^{-1}	BOD Mg L^{-1}	NH_4-N Mg L^{-1}	NO_3-N Mg L^{-1}	Suspended solids Mg L^{-1}	Dissolved solids Mg L^{-1}
Fresh water	0.53	1.45	23	9	1.3	5.5	240	530
Sewage water	1.02	4.65	127	75	17	38	920	1250
Drainage water	1.5	3.95	45	23	12	29	410	15.40

Table 3: Elemental analysis of the different sources of irrigation water during summer season 2013

Water sources	P	Zn	Mn	Fe	Cu	Cd	Pb	Co	Ni	B	Cr
Fresh water	0.31	0.00	0.05	0.02	0.00	0.007	0.032	0.02	0.0	0.06	0.30
Sewage water	0.85	0.09	0.94	0.33	0.01	0.055	0.041	0.04	0.0	0.21	0.06
Drainage water	0.41	0.01	0.02	0.21	0.00	0.001	0.084	0.08	0.0	0.01	0.03

2.3. Cultural practices and treatment details:

Maize grains (*Zea Mays,L.*) cross hybrid 321 variety was planted with cropping density 5.0 plants per m^2 in May, 2014 and harvested around september,2014. Also, cotton seeds (Gossypium Spp) were sown in March,2014 and harvested around October,2014. Weeds were controlled by integrated weed management strategies as recommeded in the area. The experimental area was (4000 m^2)for all locations ,where 800 m^2 for each location and thus the experimental plot area 40 m^2. A split-plot design was used, where main plots were assigned to the different irrigation water sources e.g. fresh water, sewage water, drainage water from (drain No. 7), drainage water alternative with fresh water and sewage water alternative with fresh. Three methods of irrigation namely; traditional surface irrigation, gated pipes and surface drip were laid in sub plots.

2.4. Water measurements:
Amount of water applied: was measured for surface and drip irrigation, while for the other modern irrigation, the water discharge was measured by flow-meter.

Surface irrigation: amount of irrigation water applied was measured by cut-throat flume (10 × 90 cm)
Water consumptive use was calculated according to the following equation:

$$\mathbf{Cu} = \sum_1^n \Theta_2 - \Theta_1 / 100 \times Bd \times 60 / 100 \times 4200$$

Where:
Cu: Water consumptive use (m^3 $acre^{-1}$.)
N : Number of irrigations
Θ_2 : Soil moisture % after irrigation
Θ_1 : Soil moisture % before the next irrigation
Bd: bulk density (Mg m^{-3}) [Israelsen and Hansen, 1962].

Water application efficiency (Ea): was calculated by using the following formula

$$\text{Ea} = \frac{water\ strend\ in\ active\ root\ zone\ m^3 / acre.}{amount\ of\ \ water\ applied\ m^3 / acre} \times 100 \qquad \text{[Downey, 1970]}$$

Field water use efficiency: is the weight of marketable crops produced per volume unit of applied water expressed as cubic meters of water [Michael, 1978].Crop water use efficiency: It was computed by dividing the yield (of crop yield per fed. by the actual water consumptive use m^3/acre [Abd El-Rasool et al., 1971].

RESULTS AND DISCUSSION

1.3. Crop yield as affected by systems and sources of irrigation water:
Egypt is one of the pioneer countries in the reuse of water. This process started as early as the 1920.s and the water multiplier now stands at 150-200%. All drainage water of the Upper Egypt returns back to the River Nile raising its salinity from about 200 ppm at Aswan to less than 300 ppm near Cairo. Four more billion cubic meters of drainage water generated in the southern part of the Delta are mixed with fresh water and reused for different purposes. It is the plan of the country to reuse another three billion cubic meter per year for the irrigation of Al Salam Canal Project (620,000 feddans or 250,000 hectares) and for the feeding of Nubaria Canal (one of the largest irrigation canals in the Western Delta which serve an area of more than seven hundred thousand acres of newly reclaimed lands.), the canal will be fed with one billion cubic meter of drainage water from Omoum Drain [El Quosy, 2005]. At present, treated sewage and industrial effluent can supply about seven million cubic meters per day or about two billion cubic meters per year. Plans to use this water for the cultivation of special crops (timber trees, industrial crops such as cotton, lax, lowers,…etc.) are under preparation.

- **Maize yield (kg $acre^{-1}$):**

Data in Fig.3 show that water sources affected the yield of maize. The highest yield of maize (3697.2 kg $acre^{-1}$)was achieved with sewage water followed by drainage water, drainage water alternative with fresh water and sewage water alternative with fresh water. The lowest yield of maize was achieved under fresh water. It could be concluded that, the maize yield obtained under both sewage and drainage water surpassed the yield obtained under fresh water by about 21.5 % and 21.3 % respectively. This trend may be attributed to that the salinity of drainage water in summer season is relatively low due to rice cultivation. Also, sewage water contains high amounts of different nutrients.

Respecting to irrigation systems and their effect on maize grain yield, data in Fig.2 indicate that, irrigation by gated pipes gave the highest values of maize yield followed by surface traditional irrigation and drip irrigation respectively. This may be attributed to good distribution and regular uniform of soil moisture during irrigation in case of gated pipes. Similar results were observed by [EL-Shafie *et al*,2009], they found regular uniform water flow from gates and regular uniform pressure head from each outlet was obtained along line at modified gated pipe under constant pressure as well as increasing crop yield under this method of irrigation.

- Cotton yield (kg acre^{-1}):

Results of seed cotton yield (kg acre^{-1}) as affected by water sources and irrigation method are presented in Fig.4. Drip irrigation achieved the highest yield of cotton yield followed by gated pipe and surface irrigation. Respecting to water sources and its effect on cotton yield, data show that the highest yield was obtained under sewage water (1305 kg acre^{-1}) and sewage water alternative with fresh water (1275 kg acre^{-1}). While, the lowest one was detected under drainage water.

The yields were increased by about 16.66, 16 and 12.98 % with sewage water under surface irrigation, gated pipe and drip irrigation, respectively. While, it was decreased by about 6.9, 4 and 13 % with drainage water under surface, gated pipe and drip irrigation system. The data also revealed, with sewage water, the gated pipe system was superior to surface and drip irrigation, while the drip irrigation was the best system with drainage water.

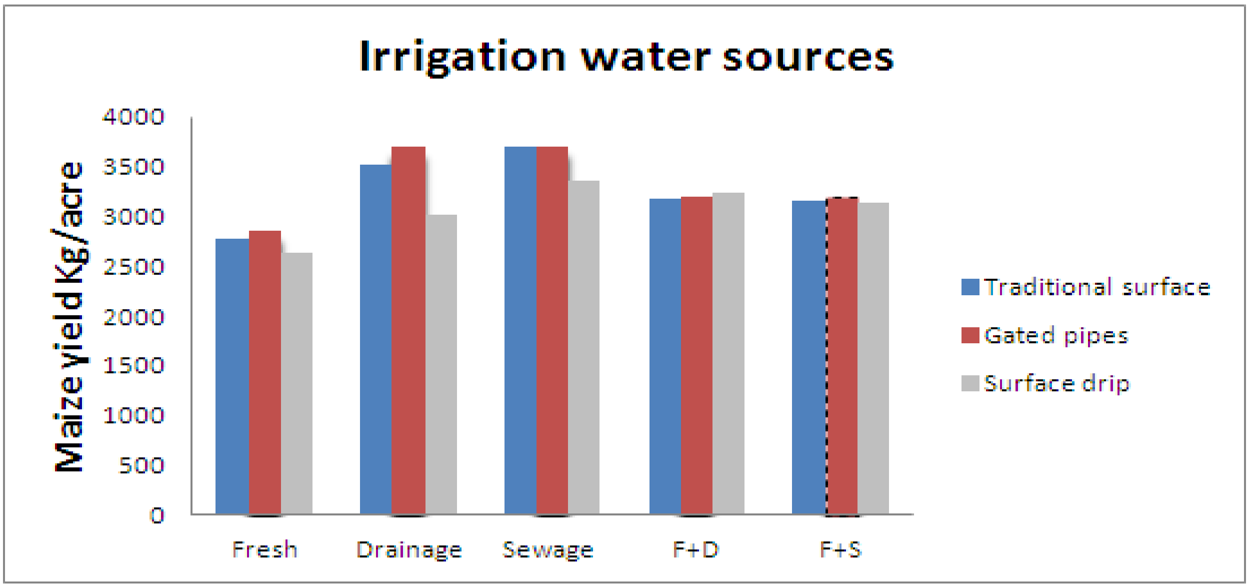

Fig.3. Effect of irrigation water sources and methods on maize grain yield

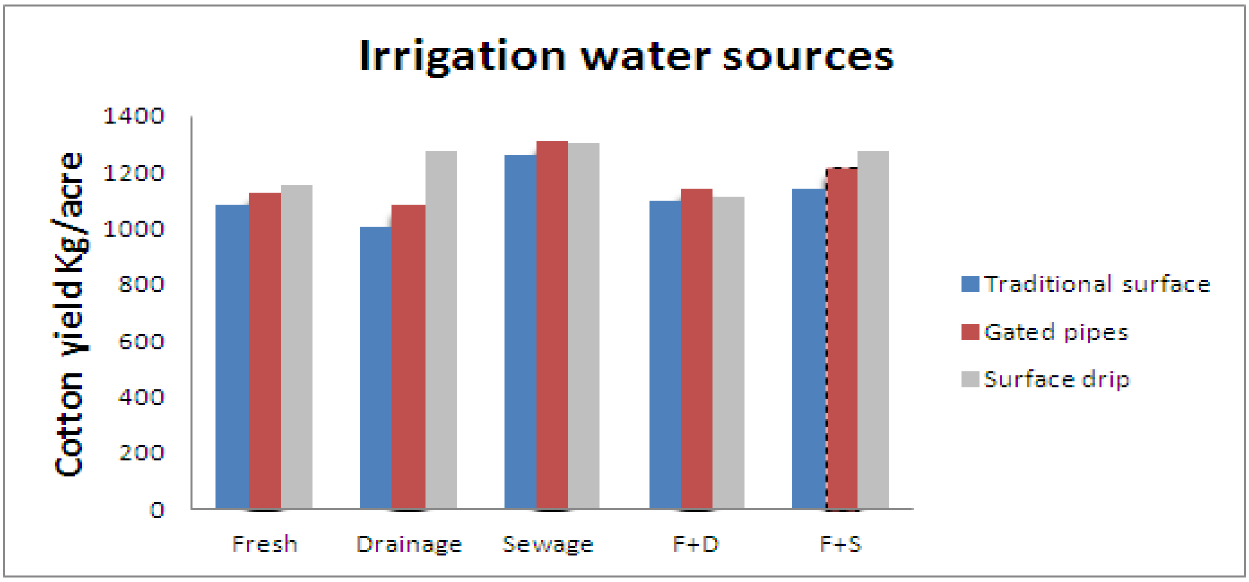

Fig.4. Effect of irrigation water sources and methods on cotton yield

1.4. Soil salt balance as affected by water quality and irrigation methods:

The chemical analysis of soil paste extraction after maize and cotton are listed in Table. 4. The data illustrated that after the cotton seasons, the continuous use of drainage water (1.3 dS m^{-1}) recorded the highest values of EC_e under surface drip and gated pipe systems (3.42, 2.86 and 3.29 dS m^{-1})respectively, followed by sewage water (1.1 dS m^{-1}) or the alternative use of both drainage and fresh water. The lowest value of EC_e were achieved by the continuous use of fresh water (0.4 dS m^{-1}) under the three irrigation systems (2.11, 2.25 and 1.83 dS m^{-1} , respectively.

SAR values approximately take the same trend of EC values. The data also revealed that the alternative irrigation alleviated the bad effect of the continuous use of drainage and sewage water.

Finally, it is worthy to mention that EC_e values achieved with all treatments after two growing seasons under the three irrigation systems are less than the harmful level (less than 4 dS m^{-1}). Also, the mean values of SAR_e for all treatments under both crops with different irrigation systems are less than the critical values since they are less than 10. This trend may be attributed to that this area has good tile drainage system.

Table.4. Salt balance of cultivated soil under maize and cotton crops

Water sources	Before exp.		Maize		Cotton	
	EC_e	SAR_e	EC_e	SAR_e	EC_e	SAR_e
			Surface irrigation			
Fresh (F)	1.49	12.6	1.32	3.56	2.11	9.23
Sewage (S)	2.25	9.19	2.04	7.86	2.84	7.07
Drainage (D)	1.64	5.18	3.88	14.68	3.42	8.81
S+F alternatives	2.14	9.62	2.01	6.44	2.21	6.5
D+F alternatives	2.38	9.81	2.18	6.31	3.11	9.14
Mean	1.98	9.28	2.29	7.77	2.74	8.15
			Drip irrigation			
Fresh (F)	2.65	11.56	1.77	6.75	2.25	4.63
Sewage (S)	4.44	12.50	2.60	9.25	2.62	8.29
Drainage (D)	3.49	7.91	2.98	11.52	2.86	9.69
S+F alternatives	2.57	9.58	2.40	7.69	2.81	9.20
D+F alternatives	3.07	9.97	2.70	7.95	3.11	7.85
Mean	3.44	10.3	2.29	8.63	2.73	7.93
			Gated pipe			
Fresh (F)	2.65	11.56	2.0	10.0	1.83	8.03
Sewage (S)	4.44	12.50	3.2	5.5	3.46	6.92
Drainage (D)	3.49	7.91	2.9	4.9	3.29	5.32
S+F alternatives	3.57	9.58	2.1	2.5	2.14	2.80
D+F alternatives	3.07	9.97	2.4	6.9	2.67	7.07
Mean	3.44	10.30	2.52	5.9	2.67	6.02

1.5. Actual water consumptive use, water applied, water application efficiency and water distribution efficiency of maize and cotton as affected by water quality and irrigation methods:

- **Actual water consumptive use:**

Regarding to maize crop water consumptive use (CU), data in Table 5 show that the highest value of CU (1981.31 m3 $acre^{-1}$) were recorded with surface irrigation, this value was decreased to 1730.5 and 1683.28 m3 acre-1 for gated pipes and drip irrigation respectively. Respecting to the effect of water sources on maize water consumption, it was noticed the highest values of CU were recorded in the treatments which were irrigated by fresh and sewage under different irrigation systems. On the other hand, the lower values were obtained with treatments irrigated with drainage water. In general, drip irrigation method consumed water less than surface and gated pipes. The same trend was observed under cotton cultivation as shown in Table.6. It was also found that the results of water use efficiency in drip irrigation were high due to the high water distribution efficiency. Maximum amount of water was available in vicinity of the plant and roots because of minimum deep percolation losses in drip irrigation system. So the maximum yield and water use efficiency was obtained in drip irrigation system. The results of water use efficiency also have good agreement with the results reported by [Khalid et al. (1999), Ahmad et al. (2001), Ibragimov et al. (2007) and Randhawa (2002)].

- **Amount of water applied:**

Referring amounts of water applied to maize crop, data in Table 5 show that, values of water applied were differed under water sources and irrigation systems. The highest value 2319.29 m^3 $acre^{-1}$ was observed under surface irrigation. Meanwhile, this value was decreased to 2058.3 and 1959.62 m^3 $acre^{-1}$ under both gated pipes and drip irrigation respectively. Therefore, it could be noticed that irrigation using gated pipes saved about 11.25 %, also drip irrigation saved about 15.5 % as compared to surface irrigation. The effect of different water sources on the amount of irrigation water applied could be arranged in the following order: S > F > S+F > D > D+F under surface irrigation; F > S > S+F > D> D+F under irrigation with gated pipes; while under drip irrigation system the sequence was: S+F > S > D+F > F > D.

Table (5): Actual water consumptive use, water applied, water application and water distribution efficiency as affected by different water sources under different irrigation methods for maize

Water sources	Actual water consumptive use, m^3 $acre^{-1}$			Amount of water applied, m^3 $acre^{-1}$						Water application efficiency, %			Water distribution efficiency, %		
	Surface	Gated pipes	Drip	Surface	Gated pipes	Water saving %	Drip	Water saving %		Surface	Gated pipes	Drip	Surface	Gated pipes	Drip
Fresh (F)	2075.64	1800.9	1678.74	2334.89	2120.6	9.17	1925.99	17.51		83.19	84.92	89.74	91.55	93.6	96.35
Sewage (S)	2028.6	1780.7	1803.06	2504.92	2100.0	16.2	1996.16	20.31		84.81	84.79	87.85	90.36	92.5	95.11
S,F alternative	2026.08	1700.0	1649.34	2313.93	2090.0	9.67	2031.9	12.18		87.16	81.33	87.94	90.40	92.7	94.78
Drainage (D)	1859.34	1680.6	1602.3	2264.97	2000.4	11.69	1904.71	15.90		76.23	84.02	84.88	90.99	95.0	97.32
D,F alternative	1916.88	1690.3	1682.94	2177.74	1980.7	9.04	1939.33	10.94		80.92	85.33	84.25	86.46	89.7	92.61
Mean	1981.31	1730.5	1683.28	2319.29	2058.3	11.25	1959.62	15.50		82.46	84.07	86.93	89.95	92.7	95.23

Table (6): Actual water consumptive use, water applied, water application and water distribution efficiency as affected by different water sources under different irrigation methods for cotton

Water sources	Actual water consumptive use, m^3 $acre^{-1}$			Amount of water applied, m^3 $acre^{-1}$					Water application efficiency, %			Water distribution efficiency, %		
	Surface	Gated pipes	Drip	Surface	Gated pipes	Water saving %	Drip	Water saving %	Surface	Gated pipes	Drip	Surface	Gated pipes	Drip
Fresh (F)	2584.3	2561.2	2427.6	3240.5	2970.0	8.37	2767.0	14.61	79.75	86.24	87.73	90.9	92.4	98.3
Sewage (S)	2628.8	2517.5	2362.1	3054.8	2842.0	6.98	2612.0	14.49	86.05	88.59	90.43	89.9	90.5	95.1
S,F alternative	2651.0	2533.0	2420.5	3123.3	2852.0	8.68	2691.0	13.83	84.88	88.81	89.94	90.1	93.5	94.9
Drainage (D)	2398.2	2325.5	2304.5	2912.5	2751.0	5.54	2592.0	11.00	82.34	84.53	88.91	88.5	95.0	95.5
D,F alternative	2483.9	2422.6	2373.0	2998.5	2866.0	4.41	2706.0	9.75	82.84	84.52	87.69	89.9	93.3	95.9
Mean	2549.2	2471.9	2377.5	3065.9	2856.0	6.79	2674.0	12.74	83.17	86.53	88.94	89.8	92.9	95.9

Respecting cotton crop, data in Table 6 clearly indicate that the drip irrigation method saved water by 12.7 %, while gated pipes saved irrigation water by 6.8 % as compared to surface irrigation. Also, fresh water received the highest amount of water applied under all irrigation systems. On the other hand, the irrigation by drainage water received the lowest amount of water applied.

It should be mentioned that, the irrigation by fresh water and sewage water alternated with fresh water saved water more than the other water sources.

- **Water application efficiency:**

As shown in Table 5 the water application efficiency for maize crop with drip irrigation exceeded both gated pipes and surface irrigation. Also, the highest value of water application efficiency was achieved with fresh water under drip irrigation method. Whereas, the lowest value was obtained with treatment irrigated by drainage water under surface irrigation method. It was noticed from data that the difference between the continuous or alternative irrigation by sewage water under drip irrigation wasn't clear. Also, the difference between the continuous irrigation or the alternative irrigation by drainage water was very small.

While, in case of cotton crop, data tabulated in Table 6 shows that the highest value of water application efficiency 88.92 % was obtained from drip irrigation followed by gated pipes (86.55%). On the contrary the lowest value 83.15% recorded from surface irrigation. Concerning the effect of different water sources, the data indicate that sewage water or sewage alternative with fresh water achieved the highest value of water application efficiency. While, the lowest values were with fresh water under surface irrigation and drainage water under gated pipe and drip irrigation.

- **Water distribution efficiency:**

The uniformity of water applied is a convenient way to judge the performance of surface or drip irrigation. It describes water distribution either of emitters discharge along the individual furrows and between the furrows. High values of water distribution efficiency means that different part of the field received similar application depths. As shown in Table 5, drip irrigation method recorded the highest values of water distribution efficiency for maize crop compared with gated pipes and surface irrigation. The highest values were obtained with the continuous irrigation by drainage water under drip irrigation. While, the lowest value was obtained with alternative irrigation by drainage water under surface irrigation. Also, the same trend was noticed with cotton crop as indicated in Table 6.

1.6. Crop and field water use efficiency of maize crop:

It was noticed that the highest values of crop and field water use efficiency were achieved with alternative drainage by fresh water treatment under drip irrigation followed by drainage water, Table (7). While, irrigation by fresh water under surface irrigation recorded the lowest values.

Table(7): Crop and field water use efficiency of maize (kg m^{-3}) as affected by different water sources and irrigation systems

Water sources	Irrigation system	CWUE kg m^{-3}	WP kg m^{-3}
F	S	1.34	1.19
	G	1.55	1.32
	D	1.56	1.36
S	S	1.72	1.4
	G	2.14	1.79
	D	1.69	1.53
S+F	S	1.56	1.36
	G	2.1	1.7
	D	1.91	1.55
D	S	1.9	1.56
	G	2.01	1.72
	D	1.88	1.59
D+F	S	1.64	1.45
	G	1.98	1.62
	D	1.98	1.72

1.7. Crop and field water use efficiency of cotton crop:

Data in Table(8) indicate that the highest values of crop and field water use efficiency were obtained under drip irrigation and gated pipes with all different water sources compared to surface irrigation. Irrigation by sewage or alternative sewage with fresh achieved the highest values of crop and field water use efficiency under drip irrigation. On the contrary, irrigation by fresh water under surface irrigation recorded the lowest value for both efficiency are similar by alternative drainage with fresh water especially under drip and gated pipe.

Table(8): Crop and field water use efficiency of cotton (kg m^{-3}) as affected by different water sources and irrigation systems

Water sources	Irrigation system	CWUE kg m^{-3}	WP kg m^{-3}
F	S	0.44	0.35
	G	0.46	0.40
	D	0.48	0.42
S	S	0.50	0.43
	G	0.55	0.48
	D	0.58	0.52
S+F	S	0.45	0.38
	G	0.51	0.45
	D	0.55	0.50
D	S	0.44	0.36
	G	0.49	0.41
	D	0.52	0.46
D+F	S	0.46	0.38
	G	0.49	0.42
	D	0.49	0.43

3.6. Socioeconomic analysis:

Several socio-economic and environmental benefits could be attained from reusing wastewater if it well organized and managed. Reusing wastewater with appropriate irrigation method could contribute in adding 340-650 USD /acre to the farmer income per year due to the crop rotation. Data in Tables (9,10 and 11) showed that reusing wastewater compensate about 60 % and 67% of N and P fertilization respectively. In addition, it sustains and conserves the existing cultivated area, creates job opportunities.

Table(9): Expected values(USD) of maize crop could be added to the farmer income due to using marginal water and different irrigation systems

Water sources	Irrigation systems					
	Surface		Gated pipes		Drip	
	Water saved m^3 $acre^{-1}$	Correspondent USD acre-1	Water Saved m^3 $acre^{-1}$	Correspondent USD $acre^{-1}$	Water saved m^3 $acre^{-1}$	Correspondent USD $acre^{-1}$
F	0.0	0.0	120.5	100.3	275.2	147.4
S	442.0	243.8	322.3	243.6	570.0	343.8
S+F	330.6	177.1	412.3	218.2	614.7	375.4
D	704.3	432.9	435.7	304.5	640.3	401.1
D+F	475.8	271.8	504.9	412.3	863.7	585.3
Mean	393.3	215.7	359.1	255.8	592.8	362.0

Table(10): Expected values(USD) of cotton crop could be added to the farmer

Water sources	Irrigation systems					
	Surface		Gated pipes		Drip	
	Water saved m^3 $acre^{-1}$	Correspondent USD acre-1	Water saved m^3 $acre^{-1}$	Correspondent USD $acre^{-1}$	Water saved m^3 $acre^{-1}$	Correspondent USD $acre^{-1}$
F	0.0	0.0	850.3	412.3	553.2	368.7
S	698.1	476.4	519.8	550.4	1268.5	1046.8
S+F	267.5	161.3	650.3	613.3	1153.1	915.0
D	83.1	47.5	300.3	630.3	814.4	594.6
D+F	256.8	154.9	313.2	602.1	618.4	422.0
Mean	262.5	158.3	526.8	561.7	884.8	654.4

income due to using marginal water and different irrigation systems.

Table(11): N and P fertilizers added to the soil through irrigation by wastewater along the whole season relative to fresh water

Water sources	Nitrogen			Phosphorus		
	Increase		Contribution %	Increase		Contribution %
	Mg L^{-1}	Kg $acre^{-1}$		*Mg* L^{-1}	Kg $acre^{-1}$	
Fresh	0.0	0.0	0.0	0.11	0.29	2.0
Drainage	12.15	30.37	43.4	0.00	0.00	0.0
Wastewater	16.71	41.77	59.7	4.04	10.1	67.4

CONCLUSION

Marginal water reuse in water resources management system reflects the application of complementary developments in technology health risk understanding and public health acceptance to mitigate limitations imposed by the increasing scarcity of water resources.

To optimize the net benefits from implementation of marginal water reuse in North Delta in Egypt, the following issues should be considered:

- Fiber crops like cotton are preferable to be cultivated when treated wastewater used in irrigation.
- Drip and gated pipes irrigation saved water by 20-25% in clay soil and increased irrigation application efficiency.
- Alternating of low quality water with fresh water can optimize the unit return due to saving 48 % of fresh water.
- Proper irrigation system with low quality water could increase farmer income by 340-60 USD /acre yearly.

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