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A Comparative Study Between Fresh and Treated Wastewater (TWW) as Alternative Water Resource on Yield and Water Productivity of Field Crops Grown in Calcareous Soil

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Abstract: In order to evaluate irrigation with treated wastewater (TWW) as an alternative irrigation source for some winter and summer crops grown in calcareous soil field trials were established to compare irrigation with secondary treated wastewater on crop yields and water productivity. Another object of the study was to determine the monetary value of the nutrients applied through TWW to different crops. Winter crops (wheat, fababean and berseem) were rotated with cotton and two types of maize (white and yellow) and were irrigated with canal water and secondary treated wastewater. The experimental design incorporates two levels of fertilizer (50 and 100% of the recommended rates of NPK for each crop) to evaluate the nutrient contribution from the treated wastewater.The quantities of nutrients and trace elements added by the treated wastewater irrigated were calculated. Nitrogen supply was on average about a third of crop requirements (this varied according to the crop and amount of treated wastewater supplied), but only a small proportion of the phosphorus, as the concentrations in the treated wastewater were very low. However, the amount of potassium supplied was approximately equal to, or in excess of, crop requirements. In the winter season, TWW provided 27 - 68 % of the recommended N rate and 21 - 81 % of the phosphorus, however, the K requirement of fababean was almost satisfied (90 %) and exceeded the needs of wheat and berseem. In the summer season, the proportion of recommended Fertilizer rates satisfied by TWW was much small than in the winter due the smaller quantities irrigated and the generally larger nutrient demands of the summer crops grown. Despite this, the TWW provided useful amounts of potassium (53 – 116 %). Phosphorus is not applied to maize as this does not normally respond to this Fertilizer. The crop yield results demonstrated that crops irrigated with secondary treated wastewater perform equally as well as, or significantly better than, with canal water. Heavy metal concentrations were very small and are of no concern to crop quality or animal and human dietary intake. There were no detectable effects of treated wastewater on soil quality.The results of cropwater productivityrevealed that there was beneficial role of TWW was greater in the winter crops compared with the summer crops. The greatest water productivity resulted from the treatment of TWW + 100 %of the recommended fertilizer for all crops. The economic input of fertilizer applied to the field crops indicate that the total NPK value ranged between 821and 3527LE according to the crop NPK requirements and the duration of irrigation. These results emphasize that the nutrients naturally present in wastewater allow savings on fertilizer expenses to be realized. The crop yield results demonstrated that crops irrigated with secondary treated wastewater perform equally as

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well as, or significantly better than, with canal water. Statistically significant improvements in crop production with treated wastewater irrigation compared with canal water were detected by the statistical analysis for fababean, white maize, yellow maize and cotton. It may be concluded from this study that under sandy calcareous desert soils in Egypt Treated wastewater can be used in field crop irrigation. However, continuous monitoring should be taken in consideration.

Key words: Treated wastewater · Field crops · Water productivity · Nutrients · Calcareous soil

INTRODUCTION

Water resources are restricted in Egypt: about 94% of water consumption originates from the Nile and is fixed at 55.5 billion cubic meters per year by an international treaty; the remaining water comes from groundwater, with a small contribution from precipitation mostly along the northern coast. Water demand will continue to increase to service agricultural and industrialrequirements, as the population and the economy expands. Consequently, there is a pressing need to reuse water wherever feasible to maximize the restricted resources available. Egypt has plans for a major expansion of its irrigation facilities with land reclamation in both the west and the eastern peripheries of the Delta, Sinai and the New Valley served by canal through Wadi Toshka. The increased demand for water can only be met by a concerted improvement in water conservation and reuse. The Egyptian Government has started a long-term series of measures to improve water scheduling, modernization of the irrigation network, the on-farm systems and reuse of drain water.

In order to support the water shortage in Egypt untraditional alternative water resources should be employed to sustain the agricultural expansion in West Delta water. The secondary treated wastewater generated from Alexandria eventually reached up to 3.5 million m^3 day^{-1}in the year 2020. From environmental point of view such quantities should be disposed of safely. Under limited water resources and drought conditions wastewater has been used to support agricultural production in many countries such as USA, Germany, India, Kuwait, Saudi Arabia, Oman, Jordan and Tunisia [1]. Several investigators indicated the beneficial role of wastewater in increasing crop yields without or with minimal risks to the plant, soil, groundwater and health [2-7].

One of the most recognized benefits of wastewater use in agriculture is the associated decrease in pressure on freshwater sources. Thus, wastewater serves as an alternative irrigation source [8], especially for agriculture, the greatest global water user, which consumes 70% of available water TWW provides a promising, unconventional water source for irrigation in Egypt[9, 10] furthermore, wastewater may be a potential source of macro- (N, P and K) and micronutrients (Ca, Mg, B, Mg, Fe, Mn or Zn) [11, 12]. Furthermore, wastewater reuse increases agricultural production in regions experiencing water shortages, thus contributing to food safety [13]. WRC[14] estimated that wastewater could offer about 30% of the crop requirements of N and 100% or more from crop requirements of K in sandy calcareous soil in Alexandria. Additionally, the nutrients naturally present in wastewater allow savings of fertilizer expenses to be realized [8, 15-17], thus ensuring a closed and environmentally favorable nutrient cycle that avoids the indirect return of macro-(especially nitrogen and phosphorous) and microelements to water bodies. Depending on the nutrients, wastewater may be a potential source of macro- (N, P and K Ca, Mg, B, Mg,) and micronutrients (Fe, Mn, or Zn) [11, 12]. Wastewater reuse has been proven to improve crop yield) [12, 17] and result in the reduced use. Therefore, the object of this work is to evaluate the efficiency of treated waste water as an alternative source for fresh water on crop productivity and water productivity from an agronomic and economic scene.

MATERIALS AND METHODS

The trials aimed to compare the use of TWW with canal(fresh) water by flood irrigation to three crops in both summer and winter seasons grown simultaneously on adjacent plots and with the crops being rotated on a three-year rotation. The trial area is divided into two equal parts for irrigation with TWW or canal water. Each part is divided into three areas for each of the selected crops and each crop area is further divided into eight irrigation basins or plots. Normal farmer practice for flood irrigation of arable crops is to divide the field into irrigation basins into which the water is channelled and this provides control of the rate and uniformity of irrigation. The irrigation basin is in effect the smallest practical plot unit for trials.

Table 1: Background chemical composition of soil

				Total concentration (mg kg^{-1} dm)											
pH	$CaCO_3$ (%)	EC (dS m^{-1})	OM (%)	N	P	K	Fe	Mn	Zn	Cu	Ni	Cd	Pb	Cr	Co
8.2	42.3	0.75	1.20	2205	6	3263	19246	193	22.3	8.8	12.5	0.3	1.7	14.0	52.5

The background chemical composition of soil is listed in Table (1).

In order to appreciate the potential nutrient value of the TWW, of the eight plots per crop and type of irrigation water, four plots receive fertilizer at the normal rate (farmer practice) and the remaining four receive half this rate. Thus there are four replicates of each Fertilizer treatment and these are randomized within each crop area. The trialdesign wasa split plot design. Calculation of the Fertilizer replacement value of the TWW for different crops indicates that TWW would provide about half of the crop's requirements of nitrogen and phosphorus and an excess of potassium. The latter is particularly important as this is an expensive fertilizer for the farmer and often not applied at rates that satisfy crop requirements (or even at all). Also P Fertilizer is not normally applied to some crops, in accordance with recommended practice. The fertilizer treatment regime to the sub-plots was as follows:

TWW Farmer practice: 100% N 100% P 100%K
Half rate Fertilizer: 50% N 50% P 0% K
Canal water Farmer practice: 100% N 100% P 100% K
Half rate Fertilizer: 50% N 50% P 50% K

Thus the 100% and 50% Fertilizer treatments is equivalent to the normal recommended application for each crop and half these amounts, respectively. No potassium Fertilizer is to be applied to the half Fertilizer plots receiving TWW since this will give an indication of the K replacement value of the TWW.

The crops selected included:

- Forage crops – multi-cuttingberseem (Meskawy).
- Seed crops which are cooked or processed – wheat Sakha-92, fababean Ciza- Blanca and grain maize Single Hybrid-10.
- Industrial crops - cotton Giza-70.

For winter crops wheat, fababean and berseem were sown on 13th November, 9th November and 13th November, respectively and seeding rates were 80, 50 and 25 kg fd^{-1} for wheat, fababean and berseem. While for summer crops maize, yellow maize and cotton were sown on 13th June, 26th May and 16th April , with seeding rates were 15, 12 and 25 kg fd^{-1} for maize, yellow maize and cotton, respectively. The area of each irrigation basin (plot) is 100 m^2 to which it was planned to apply 5-10 m^3 of TWW at each irrigation, the frequency and quantity of irrigation depending on crop and season. Summer crops generally require about twice the number of irrigations than in the winter season (Table 2), although in the winter season the amount of irrigation in this region depends on the quantity and timing of winter rainfall. The number of irrigations also tends to be fewer on this moisture-retentive soil compared with sandy soils. The timing of TWW irrigation was scheduled to coincide with the farmer's irrigation with canal water, as far as practicable. While the quantity of TWW supplied was measured precisely by the number of tanker loads delivered to each crop, it was not possible to measure the volume of canal water irrigated by the farmer.TWW was delivered directly to the individual plots from the tanker using its on-board pump through a 100 mm diameter hose. This avoids any loss of TWW by infiltration along the earth-bunded channels normally used by farmers to direct the flow of irrigation water to the irrigation basins.

The quantities of TWW irrigated to the plots, summarised in Table 3, show that the irrigation requirements of the winter season crops were more than satisfied. The normal water duty recommendations over-estimate irrigation requirements on this soil as it is water retentive.

The quantities of nutrients and trace elements applied with these quantities of TWW to each crop are summarised in Table 4, based on the average concentrations given in Tables (4 and 5). The TWW contains twice as much potassium than nitrogen (40 mg N l^{-1} compared with 18 mg N l^{-1}). The phosphorus content is very small relative tothe N and K (3.1 mg PO_4-P l^{-1}), but as this is based on orthophosphate, it will under-estimate the total quantity applied, although it may represent that which is readily available for plant uptake.

The amounts of nutrients supplied in the TWW to the crops are compared in Table 5, expressed as a percentage of the recommended Fertilizer rates for the different crops. The recommended rate is equivalent to the 100 % Fertilizer treatment in the trials. Means of macronutrients and micronutrients supplied by TWW fd^{-1} (Figs. 1 and 2).

Table 2: Irrigation frequencies as practised by farmers in the Baghdad area

Season	Crop	Number of irrigations
Winter	Wheat	6
	Fababean	2
	Berseem	7–8
Summer	Maize	5–6
	Cotton	8

Table 3: Quantities of TWW irrigated to winter and summer crops, TWW Irrigation Trial, Baghdad

	Wheat	Fababean	Berseem	White maize	Yellow maize	Cotton
No. of irrigations	5	3	6	~3	4	~12
No. of tankers	34	17	43	10	16	12
TWW supplied (m^3)	340	170	430	100	160	120
TWW applied (m^3 fd^{-1})	1789	895	2263	526	842	2630
Normal duty* (m^3 fd^{-1})	1800	940	2250	2500	2500	4000

*Based on general requirement for sandy soil which will over-estimate actual crop requirements on this heavy textured soil due to its high water retentiveness

Table 4: Quantities of nutrients and trace elements applied by TWW irrigated to winter and summer crops, TWW Irrigation Trial, Baghdad

Parameter	Wheat	Fababean	Berseem	White maize	Yellow maize	Cotton
Nitrogen (kg N fd^{-1})	32.2	16.1	40.7	9.5	15.2	10.4
Phosphorus (kg P_2O_5 fd^{-1})	12.6	6.4	16.0	3.7	6.0	4.1
Potassium (kg K_2O fd^{-1})	86.2	43.1	109.1	25.4	40.6	27.9
Zinc (g fd^{-1})	73.4	36.7	92.8	21.6	34.5	23.7
Copper (g fd^{-1})	5.4	2.7	6.8	1.6	2.5	1.7
Nickel (g fd^{-1})	22.2	11.1	28.1	6.5	10.4	7.2
Cadmium (g fd^{-1})	2.7	1.3	3.4	0.8	1.3	0.9
Lead (g fd^{-1})	74.1	37.0	93.7	21.8	34.9	24.0
Chromium (g fd^{-1})	13.2	6.6	16.7	3.9	6.2	4.3

Table 5: Percentage of recommended amounts of Fertilizer supplied by TWW to winter and summer crops

Parameter	Wheat	Fababean	Berseem	White maize	Yellow maize	Cotton
Nitrogen	32	27	68	9	14	17
Phosphorus	81	21	52	-	-	18
Potassium	359	90	455	53	85	116

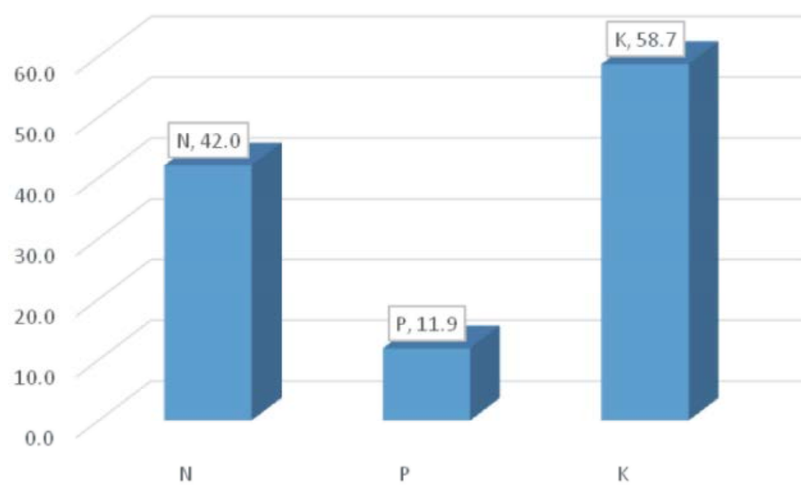

Fig. 1: Mean N, P and K nutrients supplied by treated wastewater(kg fd^{-1})

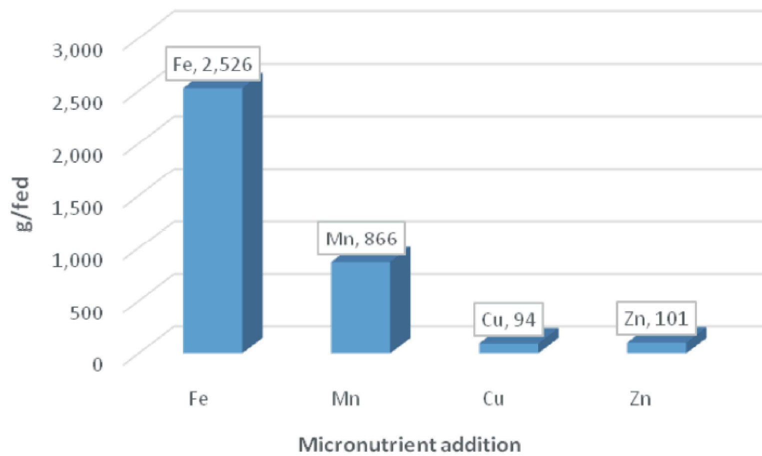

Fig. 2: Mean Fe, Mn, Cu and Zn supplied by treated wastewater(g fd^{-1})

In the winter season, TWW provided 27 - 68 % of the recommended N rate and 21 - 81 % of the phosphorus, however, the K requirement of fababean was almost satisfied (90 %) and exceeded the needs of wheat and berseem. Application of excessive amounts of K does not present any potential agronomic or environmental problems, but is held in the soil. Potassium Fertilizer is not always applied by farmers according to Egyptian recommendations because of the cost and which is likely to restrict the yield potential of many crops (Table 5). In the summer season, the proportion of recommended Fertilizer rates satisfied by TWW was much small than in the winter due the smaller quantities irrigated and the generally larger nutrient demands of the summer crops grown. Despite this, the TWW provided useful amounts of potassium (53 – 116 %). Phosphorus is not applied to maize as this does not normally respond to this Fertilizer.For trace element deficient crops, zinc is normally applied at 35 – 50 g fd^{-1}, thus TWW fully satisfied this potential requirement. However, copper is normally applied at 10 – 22 g fd^{-1}, depending on crop and level of deficiency, but the quantity of copper applied by the TWW was much smaller than this.

Yield and Chemical Determinations: Samples of treated wastewater soil were taken during crop cycle and analyzed for a range of agronomic parameters. Nutrient and heavy metal loading rates to field trials were calculated according to the irrigation quantities applied to each crop. Treated wastewaters were analyzed according to [18]. Crop yields were determined, seed, nutrient and heavy metal content were determined by [19, 20].

Water Productivity of Treated Wastewater and Canal Water: Water productivity of grown crops are indicator of effectiveness use of irrigation treated waste water compared with canal water for crop production. Water productivityseed was calculated according to [21] as follows:

$$WP_{crop} = Ey/Ir$$

where: WP_{crop} is the water productivity of crop seed (kg seed m^{-3} irrigation water), Ey is the economical yield (kg seed fed^{-1}) and Ir is the amount of applied irrigation water (m^{-3} irrigation water fed^{-1} $season^{-1}$).

Statistical Analysis: The data were subjected to statistical analysis of variance of split plot design was carried out using MSTAT-C Computer Software [22]. Means were compared by using least significant difference (LSD) at 5%.

RESULTS AND DISCUSSION

Treated Wastewater (TWW) Quality: The results of the chemical analyses were directly comparable to the overall results typical concentrations although TSS and BOD were greater in and could be attributed to the fact that the treated wastewater had been stored for several weeks after the end of the summer irrigation period and so contained algae. All of the heavy metal concentrations were 10 – 100 times smaller than the limit values in Decree 44/2000 [23] (Tables 6 and 7). Secondary treatment transfers much of the remaining heavy metal load from primary treated wastewater to sludge.

Table 6: Analysis of treatedwastewater (storage tank - mg l^{-1})

pH	DO	TSS	BOD	COD	O&G	TDS	Alk
8.3	7.8	67	59.6	158.4	-	1164	352
TKN	NO_3	NH_3	Cl	PO_4	Na	Ca	Mg
18.6	0.094	13.0	444	3.1	584	396	170
SAR	K	Cd	Cr	Cu	Pb	Ni	Zn
6.2	40	0.0015	0.0074	0.003	0.0414	0.0124	0.041

Table 7: Quality criteria for treated wastewater reuse (Decree 44/2000)

		Maximum concentration (pH 6-9)		
Parameter	Unit	Primary	Secondary	Advanced
Biological oxygen demand	mg l^{-1}	300	40	20
Chemical oxygen demand	mg l^{-1}	600	80	40
Suspended solids	mg l^{-1}	350	40	20
Oil and grease	mg l^{-1}	-	10	5
Parasite eggs	count l^{-1}	5	1	1
Faecal coliform	MPN 100 ml^{-1}	-	1, 000	100
TDS	mg l^{-1}	2, 500	2, 000	2, 000
SAR		25	20	20
Chloride	mg l^{-1}	350	300	300
Boron	mg l^{-1}	5	3	3
Cadmium	mg l^{-1}	0.05	0.01	0.01
Lead	mg l^{-1}	10	5	5
Copper	mg l^{-1}	-	0.2	0.2
Nickel	mg l^{-1}	0.5	0.2	0.2
Zinc	mg l^{-1}	-	2	2
Arsenic	mg l^{-1}	-	-	0.1
Chromium	mg l^{-1}	-	-	0.1
Molybdenum	mg l^{-1}	-	0.01	0.01
Manganese	mg l^{-1}	0.2	0.2	0.2
Iron	mg l^{-1}	-	5	5
Cobalt	mg l^{-1}	-	0.05	0.05

Notes:- no standard

Canal Water Quality: The irrigation supply in the West Nubaria area originates from the River Nile and is transferred via the Nubaria and Nasr Canals. Water quality in the Nubaria Canal is monitored on a regular basis at the potable water off-takes for Nubaria and Burg El Arab. These monitoring points are respectively upstream and downstream of the off-take for the Nasr Canal and therefore the quality of this water is representative of the chemistry of the water irrigated in the West Nubaria area. The annual mean water quality data are summarized in Table 8. The quality of the water is good for crop irrigation, with no constraints due to salinity or chloride content. Its chemistry is in marked contrast to the quality of the treated wastewater (TWW). Total dissolved solids and alkalinity are about half of that in the treated wastewater, whereas COD, chloride and nitrogen are about 25% of that in the treated wastewater. The sodium absorption ratio is about 3.2 in the canal water compared with SAR 6.2 in the treated wastewater. The nutrient content of the canal water is small, having only 4 mg N, 1.2 mg PO_4 and 10 mg K l^{-1} compared with 18 mg N, 3.4 mg PO_4 and 40 mg K l^{-1} in the treated wastewater. The potassium concentration of the canal water was estimated on the basis of its general chemistry since Na and K were reported as combined values. The microbial quality of the canal water is typical, having small numbers of faecal coliform bacteria, suggesting some contamination from sewage or animals, although the numbers are below the limit for irrigation. Parasite eggs were not reported.

Crop Yields: All of the data on crop yield components are listed in Tables (9-14) and these have been subjected to statistical analysis, which is summarised below. Yield data from six crops from the TWW Reuse Trial were examined by one-way and 2-way ANOVA to assess the effects of irrigation with secondary treated TWW and canal water at adjusted rates of Fertilizer application on yield performance. The statistical probabilities and significance of the effects of experimental treatments are

Table 8: Canal water quality at Nubaria and Burg El Arab off-takes (annual means) (Units: mg l^{-1} or as indicated)

Parameter	Nubaria	Burg El-Arab	Mean
Temperature (°C)	23.1	21.0	22.0
pH	8.2	8.2	8.2
Turbidity (NTU)	9.6	9.3	9.5
Conductivity (iS cm^{-1})	1019	1199	1109
Total dissolved solids (105 °C)	622	740	681
Total dissolved solids (180 °C)	581	683	632
Volatile solids (550 °C)	54	70	62
Total suspended solids	5	5	5
Cl^-	110	161	135
Alkalinity as $CaCO_3$	165	160	163
Total hardness as $CaCO_3$	243	274	259
Temporary hardness as $CaCO_3$	165	160	163
Permanent hardness as $CaCO_3$	78	114	96
SO_4	167	186	176
SiO_2	2.7	3.1	2.9
NO_3-N	3.63	3.46	3.55
NO_2-N	0.046	0.031	0.038
NH_4-N	0.28	0.28	0.28
PO_4-P	0.620	1.821	1.220
Ca	56.1	59.6	57.8
Mg	25.3	30.5	27.9
Na + K	116.3	142.1	129.2
Dissolved oxygen	5.53	5.55	5.54
Chemical oxygen demand	41.9	48.4	45.2
Biological oxygen demand	9.8	9	9.3
Algae count per litre	9.2×10^5	1.2×10^6	1.1×10^6
Total plate count per ml	316	450	383
Total coliforms per 100 ml	1272	478	875
Faecal coliforms per 100 ml	243	117	180

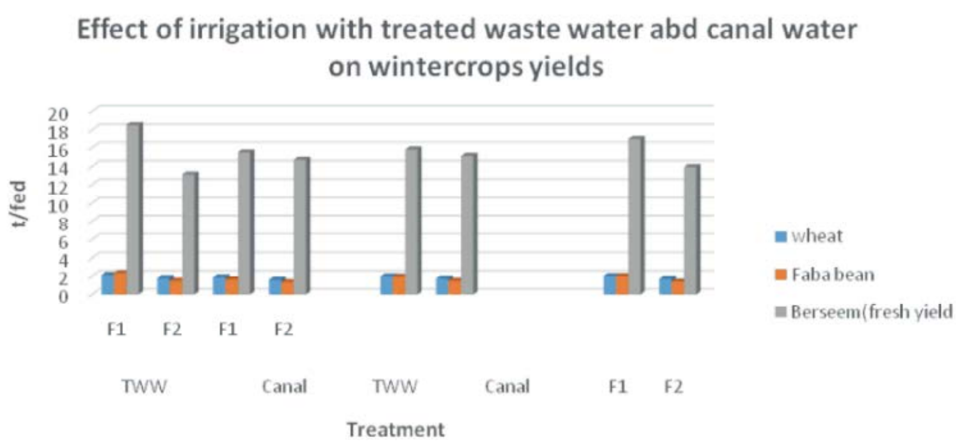

Fig. 3: Effect of irrigation with treated waste water and canal water on wintercrops yields
TWW: Treated waste water F1: 100 % NPK Fertilizer F2: 50% NPK Fertilizer

shown in Tables (9– 14) with the individual treatment means and main effect mean values. The main economic yield parameters of the crops are also plotted in Figures (3 and 4). The results demonstrate that crops irrigated with secondary treated TWW perform equally as well as, or significantly better than, with canal water. Statistically significant improvements in crop production with TWW irrigation compared with canal water were detected by the statistical analysis for fababean, white maize, yellow maize and cotton. Wheat and berseem yields obtained with TWW were not statistically significant from those measured on plots irrigated with canal water. Nevertheless, the results indicated that there was also a general trend of yield improvement with TWW irrigation for these crops (Figures3 and 4).Treated TWW potentially contributes a significant portion of the nutritional requirements of crops and the inorganic Fertilizer treatments were adjusted to examine this aspect. In general, two rates of mineral Fertilizer were supplied including the full recommended rate of NPK and also at

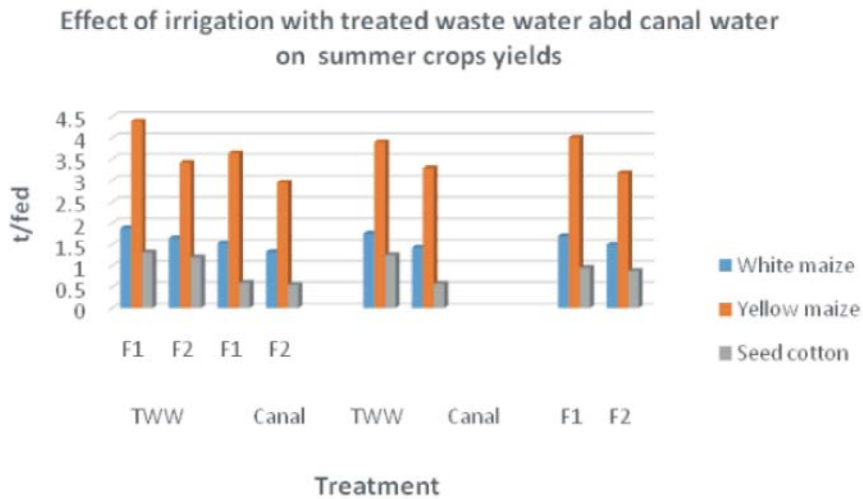

Fig. 4: Effect of irrigation with treated waste water and canal water on summer crops yields
TWW: Treated wastewater F1: 100 % NPK Fertilizer F2: 50% NPK Fertilizer

Table 9: Wheat yield components and statistical probabilities and significance of treatment effects and interactions

Source of variation and treatment		1000 Grain weight(g)	Strawyield (t fd^{-1})	Grain yield (t fd^{-1})	Biological yield (t fd^{-1})
Statistical probabilities from 2-way ANOVA					
Irrigation		0.039*	0.266ns	0.402ns	0.185ns
Fertilizer		0.801ns	0.066ns	0.262ns	0.042*
Irrigation x Fertilizer		0.454ns	0.221ns	0.881ns	0.345ns
Individual treatment means					
TWW	N100/P100/K100	55.0a	8.13a	2.11a	10.2a
TWW	N50/P50/K0	55.5a	7.82a	1.77a	9.6a
Canal	N100/P100/K100	53.5a	8.18a	1.85a	10.0a
Canal	N50/P50/K50	52.5a	6.82a	1.58a	8.4a
Main effect treatment means					
TWW		55.3a	7.98a	1.94a	9.92a
Canal		53.0b	7.50a	1.72a	9.21a
100% Fertilizer		54.3a	8.15a	1.98a	10.1a
50% Fertilizer		54.0a	7.32a	1.68a	9.0b

Values within a column for each mean category, followed by the same letter, are not significantly different at P=0.05

Table 10: Fababean yield components and statistical probabilities and significance of treatment effects and interactions

Source of variation and treatment		Plant height (cm)	Branches plant^{-1}	Pods plant^{-1}	Straw yield (t fd^{-1})	100 Seed weight (g)	Seed yield (t fd^{-1})	Biological yield (t fd^{-1})
Statistical probabilities from 2-way ANOVA								
Irrigation		0.245ns	0.002**	0.004**	0.032*	0.029*	0.026*	0.016*
Fertilizer		0.619ns	0.338ns	0.333ns	0.084ns	0.453ns	0.005**	0.081ns
Irrigation x Fertilizer		0.058ns	0.277ns	0.028*	0.683ns	0.762ns	0.104ns	0.956ns
Individual treatment means								
TWW	N100/P100/K100	102a	6.5a	23a	4.62ab	121a	2.33a	7.35ab
TWW	N50/P50/K0	91a	5.4ab	20a	3.14b	120a	1.47b	4.60b
Canal	N100/P100/K100	79a	3.8b	10b	7.48a	114a	1.62b	9.13a
Canal	N50/P50/K50	97a	3.9b	17ab	5.16ab	111a	1.34b	6.49ab
Main effect treatment means								
TWW		97a	5.9a	21a	3.88b	120a	1.90a	5.97a
Canal		88a	3.8b	13b	6.32a	112b	1.48b	7.81a
100% Fertilizer		91a	5.1a	16a	6.05a	118a	1.98a	8.24a
50% Fertilizer		94a	4.6a	18a	4.15a	115a	1.40b	5.55b

Values within a column for each mean category, followed by the same letter, are not significantly different at P=0.05

Table 11: Berseem yield and statistical probabilities and significance of treatment effects and

Source of variation and treatment		First cut FW (t fd^{-1})	Second cut FW (t fd^{-1})	First cut dm (t fd^{-1})	Second cut dm (t fd^{-1})	Total FW (t fd^{-1})	Total dm (t fd^{-1})
Statistical probabilities from 2-way ANOVA							
Irrigation		0.453ns	0.809ns	0.289ns	0.299ns	0.568ns	0.859ns
Fertilizer		0.038*	0.084ns	0.370ns	0.038*	0.026*	0.043*
Irrigation x Fertilizer		0.107ns	0.192ns	0.087ns	0.252ns	0.084ns	0.076ns
Individual treatment means							
TWW	N100/P100/K100	8.24a	10.23a	1.09a	1.53a	18.5a	2.62a
TWW	N50/P50/K0	5.56a	7.51a	0.82a	1.09a	13.1b	1.91b
Canal	N100/P100/K100	6.58a	8.87a	0.80a	1.52a	15.5ab	2.32ab
Canal	N50/P50/K50	6.20a	8.45a	0.89a	1.38a	14.7ab	2.27ab
Main effect treatment means							
TWW		6.90a	8.87a	0.95a	1.31a	15.8a	2.26a
Canal		6.39a	8.66a	0.85a	1.45a	15.1a	2.29a
100% Fertilizer		7.41a	9.55a	0.94a	1.53a	17.0a	2.47a
50% Fertilizer		5.87b	7.98a	0.86a	1.23b	13.9b	2.09b

Values within a column for each mean category, followed by the same letter, are not significantly different at P=0.05

Table 12: White maize yield components and statistical probabilities and significance of treatment effects and

Source of variation and treatment		Plant height (cm)	Stand at harvest (×10^3 plants fd^{-1})	Straw yield (t fd^{-1})	Grain yield (t fd^{-1})	Biological yield (t fd^{-1})
Statistical probabilities from 2-way ANOVA						
Irrigation		0.005**	0.355ns	0.002**	0.044*	0.001**
Fertilizer		0.071ns	0.258ns	<0.001***	0.175ns	<0.001***
Irrigation x Fertilizer		0.365ns	0.262ns	0.001**	0.943ns	0.013*
Individual treatment means						
TWW	N100/P0/K100	212a	15.2a	4.21ab	1.88a	6.09a
TWW	N50/P0/K0	210ab	13.6a	3.59b	1.65a	5.24a
Canal	N100/P0/K100	209b	13.7a	4.26a	1.53a	5.79a
Canal	N50/P0/K50	208b	13.7a	2.32c	1.32a	3.64b
Main effect treatment means						
TWW		211a	14.4a	3.90a	1.76a	5.66a
Canal		208b	13.7a	3.29b	1.42b	4.71b
100% Fertilizer		210a	14.4a	4.24a	1.70a	5.94a
50% Fertilizer		209b	13.6a	2.95b	1.49a	4.44b

Values within a column for each mean category, followed by the same letter, are not significantly different at P=0.05

Table 13: Yellow maize yield components and statistical probabilities and significance of treatment effects and interactions

Source of variation and treatment		Plant height (cm)	Stand (×10^3 plants fd^{-1})	Ears per plant	Ear diameter (cm)	Ear weight (g)	Straw yield (t fd^{-1})	Seed yield (t fd^{-1})	Biological yield (t fd^{-1})
Statistical probabilities from 2-way ANOVA									
Irrigation		<0.001***	0.663ns	<0.001***	<0.001***	<0.001***	<0.001***	0.022*	<0.001***
Fertilizer		0.398ns	0.762ns	0.133ns	0.246ns	0.017*	<0.001***	0.004**	<0.001***
Irrigation x Fertilizer		0.727ns	0.240ns	0.424ns	0.837	0.221ns	0.037*	0.553ns	0.326ns
Individual treatment means									
TWW	N100/P0/K100	256a	18.5a	1.38a	4.9a	336a	5.64a	4.39a	10.0a
TWW	N50/P0/K0	252a	20.1a	1.35ab	4.9a	314a	5.10a	3.41b	8.51b
Canal	N100/P0/K100	218b	20.3a	1.21bc	4.6b	281ab	4.97a	3.64ab	8.61b
Canal	N50/P0/K50	208b	19.3a	1.12c	4.5b	219b	3.54b	2.95b	6.48c
Main effect treatment means									
TWW		254a	19.3a	1.36a	4.9a	325a	5.38a	3.90a	9.27a
Canal		213b	19.8a	1.17b	4.6b	250b	4.26b	3.29b	7.55b
100% Fertilizer		237a	19.4a	1.29a	4.8a	308a	5.31a	4.01a	9.32a
50% Fertilizer		230a	19.7a	1.23a	4.7b	266b	4.32b	3.18b	7.50b

Values within a column for each mean category, followed by the same letter, are not significantly different at P=0.05

Table 14: Cotton yield components and statistical probabilities and significance of treatment effects and interactions

Source of variation and treatment	Plant height (cm)	Open bolls plant^{-1}	Closed bolls plant^{-1}	Total bolls plant^{-1}	Straw yield (t fd^{-1})	Seed cotton yield (t fd^{-1})	Biological yield (t fd^{-1})
Statistical probabilities from 2-way ANOVA							
Irrigation	0.001**	<0.001***	<0.001***	<0.001***	<0.001***	<0.001***	<0.001***
Fertilizer	0.442ns	0.161ns	0.958ns	0.517ns	0.965ns	0.375ns	0.891ns
Irrigation x Fertilizer	0.456ns	0.609ns	0.873ns	0.723ns	0.293ns	0.717ns	0.294ns
Individual treatment means							
TWW N100/P100/K100	150a	17a	14a	31a	4.85a	1.31a	6.15a
TWW N50/P50/K0	138ab	16a	14a	30a	4.45a	1.20a	5.65a
Canal N100/P100/K100	111b	10b	5b	15b	1.79b	0.60b	2.39b
Canal N50/P50/K50	111b	10b	5b	15b	2.22b	0.55b	2.77b
Main effect treatment means							
TWW	143a	17a	14a	31a	4.65a	1.25a	5.90a
Canal	111b	10b	5b	15b	2.01b	0.58b	2.58b
100% Fertilizer	130a	14a	9a	23a	3.32a	0.95a	4.27a
50% Fertilizer 124a	13a	9a	22a	3.34a	0.88a	4.21a	

Values within a column for each mean category, followed by the same letter, are not significantly different at P=0.05

50 % of the normal inputs. TWW is particularly enriched with K relative to crop needs for this essential plant nutrient, which was omitted from the Fertilizer supplied to the half-rate plots irrigated with this water source. The N and P balance was modified according to the agronomic requirements of the different crop types. Fertilizer application at the recommended rate significantly increased total wheat yield (straw and grain); seed production by fababean; total berseem production; straw yield of white maize; straw and seed yield of yellow maize, compared with the adjusted lower rate of addition. The only crop not responding significantly to the higher input of Fertilizer compared to the modified rate, was cotton.

There were only two cases where a statistically significant interaction between irrigation type and Fertilizer rate was detected by ANOVA, including the number of pods per plant on fababean (Table 10) and straw yield of white maize (Table 12). In the latter case, the interaction was explained by the magnitude of the increase in straw yield measured on plots irrigated with canal water compared with treated TWW. Generally, however, yields were raised to a similar extent by the full rate of Fertilizer application compared to the half rate for both sources of irrigation water. Potassium was withheld from most of the crops receiving the adjusted rate of Fertilizer and irrigated with treated TWW, but was supplied with canal water. Trace element deficiencies in crops are common in Egypt due to the calcareous nature of most soils. TWW applied useful quantities of zinc but the amount of copper applied is small. The additions of heavy metals were very small, with the exception of lead, which was present in the TWW at a similar concentration as zinc.

The absence of a significant interaction between irrigation and Fertilizer application could therefore indicate the adequacy of the K resources applied to soil in the TWW for crop production. This could be confirmed by calculating the nutrient balance of K supplied in the TWW relative to its offtake in harvested crop components. Liu and Haynes (2011) [24] and [11] indicated that depending on the nutrients, wastewater may be a potential source of macro- (N, P and K) and micronutrients (Ca, Mg, B, Mg, Fe, Mn or Zn). Several investigators obtained yield increases due to wastewater application [5, 14, 25, 26] Such increase in crop yields due to wastewater irrigation could be attributed to the nutrient content in relation to specific crop requirements. In this respect, [27] stated that weekly application of 25 mm wastewater was enough to supply 40-80% of corn requirements and all of P requirements while other researchers pointed out that the increase in corn yield was due to the enhancement of nutrient uptake and the improvement of the physical properties of the soil. Indeed, wastewater reuse has been proven to improve crop yield [12, 17] and result in the reduced use of fertilizers in agriculture [28].

Data presented in Table 15 and Figs. 5 and 6 reveal that the beneficial role of TWW was greater in thewinter crops compared with the summer crops. The greatest water productivity resulted from the treatment of TWW + 100 %of the recommended fertilizer for each crop (F1). From the same table, the data show that with the exception of berseem TWW gave higher water productivity kg m^{-3} than the canal (fresh) water. Also, the application of 100% of the recommended fertilizer surpassed the reduced rate (50%) of the recommended dose for all crops regardless of the other treatment.

Table 15: Water productivity for winter and summer crops (kgm^{-3})

		Water productivity (kgm^{-3})					
		Wheat	Fababean	Berseem	White maize	Yellow maize	Cotton
TWW	F1	1.179a	2.603a	1.158a	0.752a	1.756a	0.328a
	F2	0.989ab	1.642ab	0.844b	0.660b	1.364a	0.300a
Canal	F1	1.034a	1.810ab	1.025a	0.612b	1.456a	0.150b
	F2	0.883b	1.497b	1.003a	0.528c	1.180a	0.138b
TWW		1.084a	2.123a	0.999a	0.704a	1.560a	0.313a
Canal		0.961b	1.654b	1.012a	0.568b	1.316a	0.145b
F1		1.107a	2.212a	1.091a	0.680a	0.680a	0.238a
F2		0.939b	1.564b	0.924a	0.596b	0.596a	0.220a

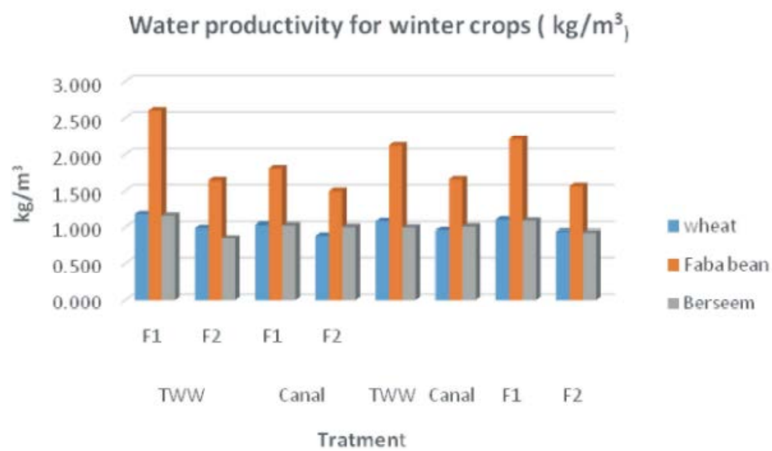

Fig. 5: Effect of irrigation with treated waste water and canal water on winter crops water productivity (kgm^{-3})
TWW: Treated waste water F1: 100 % NPK Fertilizer F2: 50% NPK Fertilizer

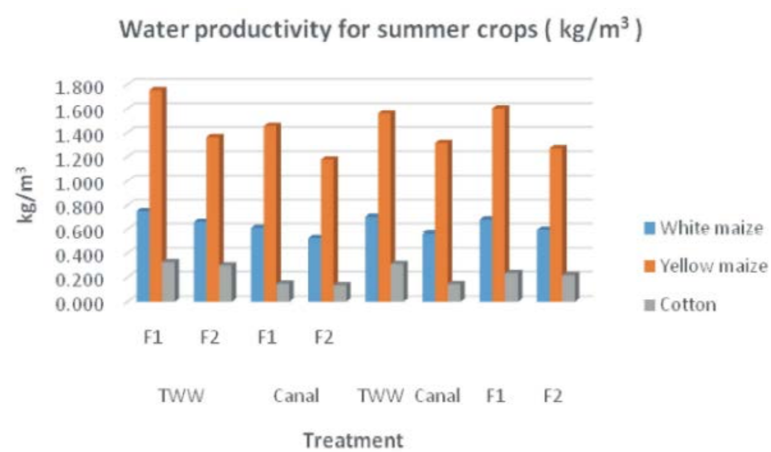

Fig. 6: Effect of irrigation with treated waste water and canal water on summer crops water productivity (kgm^{-3})
TWW: Treated waste water F1: 100 % NPK Fertilizer F2: 50% NPK Fertilizer

Table 16: Monetary Value (EG P) for N, P and K applied to irrigated field crops through TWW

Macronutrient	Wheat	Fababean	Berseem	White maize	Yellow maize	Cotton
Nitrogen	612	306	773	181	289	198
Phosphorus	195	99	248	57	93	63
Potassium	1121	560	1418	330	528	363
Total LE	1927	965	2439	568	909	624

Table 17: Monetary Value (EG P) for Zn, Cu, Fe and Mn applied to irrigated field crops through TWW

Micronutrient	Wheat	Fababean	Berseem	White maize	Yellow maize	Cotton
Zn	282.6	141.3	357.3	83.2	132.8	91.2
Cu	12.4	6.2	15.6	3.7	5.8	3.9
Fe	254.3	127.2	321.6	74.8	119.5	82.1
Mn	310.8	155.4	393.0	91.5	146.1	100.4
Total LE	860.2	430.1	1087.5	253.2	404.2	277.6

Table 18: Total Monetary Value (EG P) for macro and micronutrients applied to irrigated field crops through TWW

	Wheat	Fababean	Berseem	White maize	Yellow maize	Cotton
Macronutrients	1927.448	965.272	2439.28	567.976	909.48	623.768
Micronutrients	860.2	430.1	1087.5	253.2	404.2	277.6
Total Value LE	2787.6	1395.4	3526.8	821.1	1313.7	901.4

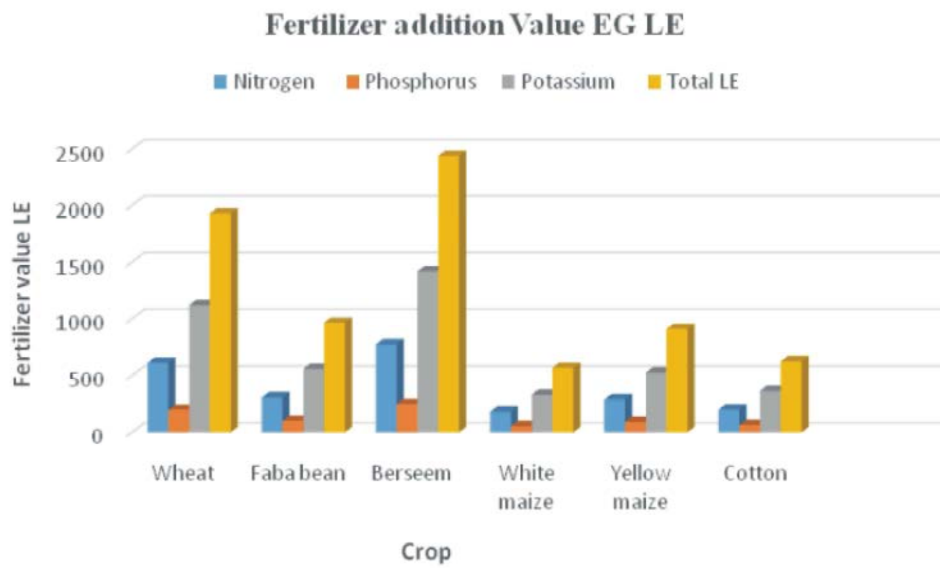

Fig. 7: Fertilizer addition Monetary Value (EG P) for N, P and K applied to irrigated field crops through TWW

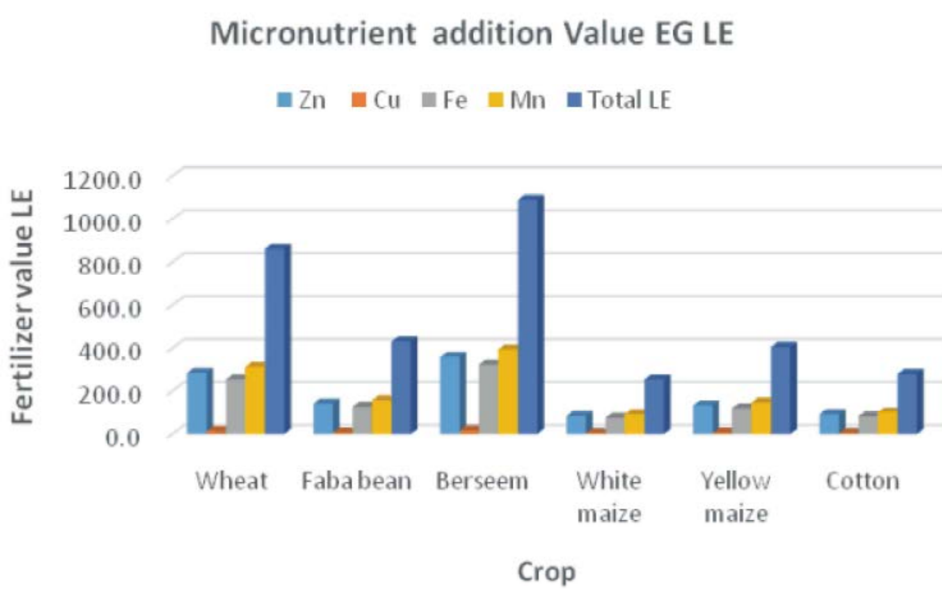

Fig. 8: Fertilizer addition Monetary Value (EG P) for Zn, Cu, Fe and Mn applied to irrigated field crops through TWW

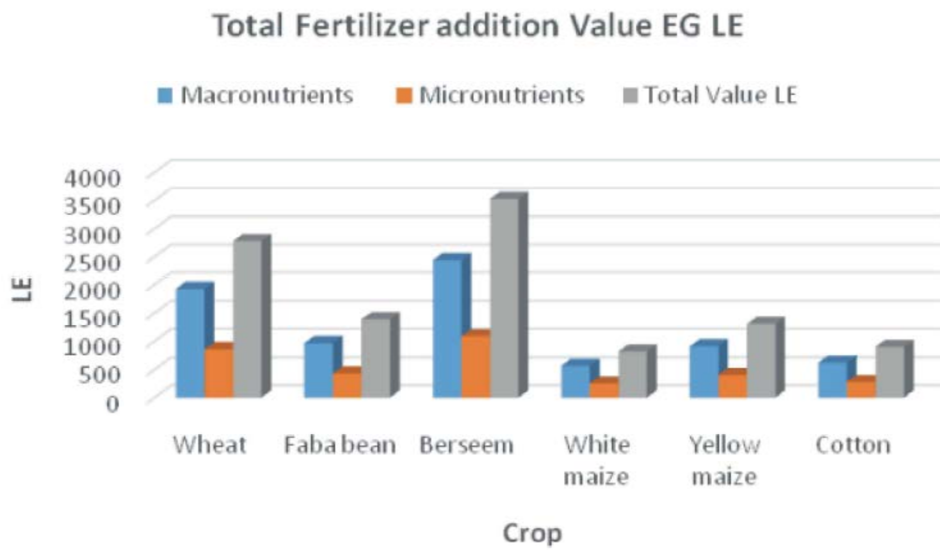

Fig. 9: Total fertilizer addition Monetary Value (EG P) for N, P and K applied to irrigated field crops through TWW

Generally, the lowest water productivity value was recordedmarkedly for cotton and this may be due to the longer growing season and the higher crop requirements than the other crops. The superiority of TWW in producing water productivity over the canal water could be attributed to the nutrient supplied (Table) compared to the canal water since a proportion of the nitrogen and phosphorus requirements of the crop, but generally adequate levels of potassium. The crop yield responses showed conclusively that additional fertilizer is necessary to achieve reasonable crop water productivity. The obtained results demonstrate the importance of applying supplementary fertilizer at appropriate levels for the crop and soil and emphasize that the nutrients naturally present in wastewater which allow savings on fertilizer expenses to be realized [8, 15-17]. The advantage of field crop irrigation with treated wastewater is evident from agronomic and economic scene. Several investigators assured that the nutrients naturally present in wastewater allow savings on fertilizer expenses to be realized [8]. Also, [8, 11, 24] indicated that depending on the nutrients, wastewater may be a potential source of macro- (N, P and K) and micronutrients (Ca, Mg, B, Mg, Fe, Mn or Zn).

The economic value of treated wastewater Considerable amounts of macronutrients (NPK) were applied to the grown crops through the treated wastewater irrigation. Table (6) shows the calculation of fertilizer value in EGP based on market prices in Egypt. Nitrogen addition ranged between 181 and 612 EGP, P between 57 and 248 while K ranged between 330 and 1121 EGP (LE) according to the crop and the period of wastewater irrigation. Regarding micronutrients the value of Zn applied through TWW ranged between 83.2 and 367.5 LE, Cu 3.7 and 15.6LE, Fe 74.8 and 321.6LE, Mn 91.5 and 393.5 LE according to the crop, (Fig. 8). The total value for micronutrient applied through TWW ranged between 253.2 and 860.2LE according to the crop. The most beneficial value of N, P and K was reported by cotton (Fig. 7). This could be attributed to the longer period of cotton irrigation with treated wastewater than other crops. The Economic input of fertilizer applied to the field crops indicate that the total NPK value ranged between 821and 3527LE according to the crop NPK requirements and the duration of irrigation These results emphasize that the nutrients naturally present in wastewater allow savings on fertilizer expenses to be realized [8, 15 17, 24].

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