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Long-term Impact of Irrigation with Marginal Water on some Soil Properties

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ABSTRACT

A permanent lyzimeter experiment has been conducted since 1987 at Sakha Agric. Res. Station, Kafer El-Sheikh, Egypt to monitor the changes occurred in the soil properties as a result of using a marginal waste water in irrigation through years of 1993, 2000, 2007 and 2014.The results revealed that, the soil salinity exceeded the limiting value of EC > 4 dS/m in 2000 and 2007 with using the marginal waste and the mixture waters in irrigation, respectively, indicating that the soil started to be saline. Irrigation with the mixture water mitigated the hazardous effect of using the marginal waste water in irrigation since the soil salinity was reduced by 27.16, 33.70, 35.47 and 41.25% in 1993, 2000, 2007 and 2014, respectively, due to using the mixture water. Prolonged applications of marginal waste water (more than 25 years) did not cause soil sodicty since the ESP values in all treatments were less than the critical limit (ESP < 15). The soil organic matter content was relatively higher with using the low quality water in irrigation for a long time than with using Nile water. The organic matter content in the soil irrigated by the marginal waste water was 1.03 and 2.21% in 1993 and 2014 respectively. The comparable soil organic matter values in the respective years were 0.79 and 1.94% for mixture water irrigation as well as 0.72 and 1.14% for Nile water irrigation. On an average basis, the prolonged application of marginal waste water (more than 25 years) resulted in an increase in the total soil Nitrogen by 50.00%, soil phosphorus by 30.46% and soil potassium by 50.66% compared to those in the Nile water irrigated soil. Soil iron, manganese and cupper increased by 29.63, 7.26 and 34.85%, respectively in 2014 when the soil irrigated by marginal waste water compared to those of the soil irrigated by Nile water in this year.

Key words: Marginal waste water, Nile water, soil salinity, soil sodicity, organic matter

Introduction

Increasing global population widens the gap between water supply and its demand, especially in arid and semi-arid regions. Reaching a such alarming level in some parts of the world causes a threat to human existence. Scientists around the world are working how to get new ways of conserving water (Nilarekha and Ambujam, 2012). Wastewater is considered an attractive source for irrigation in these countries because available and nonexpensive (Al-Rashed & Sherif, 2000; Mohammad & Mazahreh, 2003). Each source of water which might be used economically and effectively should be considered to promote further development (Asano, 2002). It can help to close the loop between water supply and wastewater disposal. However, in most countries, regulations or specific guidelines for greywater reuse are not available. Therefore, this water is often used without any significant pre-treatment, a practice mistakenly considered safe (Gross *et al*., 2003; Wiel *et al*., 2006).

On the other hand, disposal of municipal wastewater and industrial effluents causes major environmental problems and many attempts are being made all over the world to recycle and reuse these waters efficiently. Disposal of waste water contributes to nutrient cycling, although pollutants that may accumulate in the soils can cause a potential risk to the soil quality and productivity with time (Friedel *et al*. 2000 ; Mohammad & Mazahreh, 2003). In fact, the long-term impact of irrigation with poor quality waters on physico-chemical properties of soils depends upon the interaction of several factors, such as the unique water quality limiting parameters as well as site-specific crop, soil and climatic conditions (Minhas and Gupta, 1992). Consequently, the reuse of wastewater for irrigation can lead to an accumulation of these pollutants in the soils that affect their fertility and productivity. Treated wastewater can also be a source of chemical substances, such as salts, heavy metals, and surfactants. These substances might then accumulate in the soils, with unfavorable effects on crop quality and production, and ecological soil conditions (Gatta, *et al*., 2015).

Egypt, as a semi-arid country, suffers from a shortage in water supply for domestic, industrial and agricultural purposes. Hence, limited water supplies require careful management for successful agricultural production. Meanwhile, using drainage and/or sewage water in irrigation significantly increase the total and DTPA

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extractable heavy metals in soils of Egypt (Zein *et al*., 2002). A reduction in the soil pH and increases in the organic matter, total N,P,K and heavy metal contents were observed at sites receiving high amounts of sewage water for irrigation (Yadav *et al*., 2002 ; Fatih *et al*., 2007 ; Wang & Wang 2005 ; Wang *et al*., 2007). Mohammad & Mazahreh, (2003) reported that the soil that irrigated with wastewater showed a decrease in the soil pH and an increase in the soil salinity, phosphorus (P), potassium (K), iron (Fe), and manganese (Mn) level.

Rattan *et al.* (2005) found that the irrigation with sewage water for 20 years resulted in an increase in the soil organic carbon content that ranged from 38 to 79% compared to that irrigated with tap water ; the soil pH was dropped by 0.4 unit and significant build-up of DTPA-extractable Zn (208%), Cu (170%), Fe (170%), Ni (63%) and Pb (29%) in the sewage water-irrigated soils was over those of the adjacent Tap water-irrigated ones. Moreover, Kiziloglu *et al*. (2008) reported that use of wastewater in irrigation increased the soil salinity, organic matter, exchangeable Na, K, Ca and Mg as well as available phosphorus and microelements, but it decreased soil pH. Using drainage water in irrigation causes a high increase in the EC and SAR of the saturated soil paste extract (Omar *et al*., 2001; Fatih *et al*., 2007; Atwa *et al*., 2013).

This study aims to evaluate some soil chemical properties and the possible accumulation of macro and micro nutrients in a soil irrigated with untreated marginal waste water.

Material and Methods

A permanent lyzimeter experiment has been carried out since 1987 at Sakha Agric. Res. Station, Kafer El-Sheikh, Egypt. It aims to monitor the changes occurred in the soil chemical properties as a result of using a marginal waste water in irrigation through years of 1993, 2000, 2007 and 2014. Cement lyzimeters (100cm in length x 70 cm in width x 90 cm in high) were filled by a clay soil; they were intermittently supplied with minimum amounts of tap water to insure a complete settling of the soil. The soil properties are present in Table (1).

Table 1: Some chemical properties of the soil before the irrigation with the investigated water types.

Soluble ions (meq/l)							ECe (dS/m)	SAR	pH (1:2.5)	SP (%)
Ca^{++}	Mg^{++}	Na^{+}	K^{+}	CO_3^{+} / HCO_3	Cl	SO_4				
6.00	7.26	6.47	0.28	1.00	9.01	10.00	2.00	2.64	7.73	75.90
Clay (%)	Silt (%)	Sand (%)	Texture	OM (%)	N (%)	Total nutrient (mg/kg)				
						P	K	Fe	Mn	Cu
58.00	16.00	26.00	Clay	0.70	0.07	501.0	520.0	1450.0	570.0	120.0

The lyzimeters have been irrigated by three different water types. The water types were a) Nile water, W_n b) marginal waste water (sewage , industrial and drainage water) W_{mw} and c) mixture of both previous types of 1:1 ratio W_m. The chemical analysis of those irrigation waters is shown in Table (2).

Table 2: Chemical analysis of waters used to irrigate the studied soils.

Irrigation	Soluble ions (meq/L)								EC	pH	SAR	Water
water	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	$CO_3^{=}$	HCO_3^{-}	Cl^{-}	$So_4^{=}$	(dS/m)			class
Nile water	1.82	1.49	1.54	0.35	-	2.46	1.62	1.12	0.52	8.00	1.20	C_2-S_1
Marginal waste water	4.10	2.08	11.41	0.61	-	3.90	10.80	3.50	1.82	8.20	6.49	C_3-S_2

Irrigation water	Micro nutrient (mg/L)		
	Fe	Mn	Cu
Nile water	0.100	0.011	0.012
Marginal waste water	0.267	0.337	0.053
Critical limits according FAO (1989)	0.500	0.200	0.200

The lyzimeter experiment was arranged in a complete randomized design with four replications. Soil samples were taken from each treatment at 30 cm soil depth in July, 1993 and repeated each seven years, then air-dried, ground, to sieve through a 2mm screen and kept in plastic jars for chemical analysis. The chemical analysis of soil and water was carried out according to Page *et al*. (1982). Exchangeable sodium percentage was estimated using the equation out lined by Richards (1954) as follows:-

$$ESP = (100(-0.0126+ 0.01475X))/ 1+ (-0.0126 + 0.01475X)$$

ESP = Exchangeable sodium percentage X = Sodium adsorption ratio

The soil samples were digested with a mixture of 350 ml H_2O_2, 0.42 g Se powder, 14.0 g $LiSO_4.H_2O$ and 420 ml concentrated H_2SO_4 to determine total N, P ,K and micronutrients (Cu, Mn and Fe) according to Parkinson and Allen (1975). The digestion of a suitable amount of soil samples (≈0.2g) was performed in digestion flask with 5.0 ml of a digestion mixture solution by heating with a starting temperature of 50 C^{o} that ends to 350 C^{o} for 6 hours.

Results and Discussion

Soil salinity and soluble ions.

Generally, data in Table (3) clearly indicated that all water types used in irrigation increased the soil salinity and soluble ions as the time proceed. The soil salinity expressed as an electrical conductivity (EC_e) increased from 2.10 dS/m in 1993 to 3.59 dS/m in 2014 when the soil was irrigated by Nile water (W_n). Moreover, it was increased by 18.57, 43.81 and 70.95% in 2000, 2007 and 2014, respectively, compared to that year 1993 by using W_n in irrigation. However, after almost 25 years from using Nile water in irrigation, the soil salinity still in the normal range since it does not exceed 4 dS/m which is considered the limiting value of saline soil. On the other hand, the soil salinity increased from an EC_e value of 2.46 dS/m in 1993 to 5.04 dS/m in 2014 when the soil was irrigated by the mixture water (W_m).

Table 3: Effect of irrigation by different types of water on soil chemical properties during the study period (1987- 2014).

Water treatment	Year	Soluble Ions (mq/L)							ECe (dS/m)	SAR	ESP (estimated)	OM (%)	pH (1: 2.5)
		Ca^{++}	Mg^{+2}	Na^{+}	K^{+}	$CO_3^{=}$ + HCO_3^{-}	Cl^{-}	$So_4^{=}$					
Initial	1987	6.00	7.26	6.47	0.28	1.00	9.01	10.00	2.00	2.64	3.81	0.70	7.73
W_n	1993	6.22	8.00	7.10	0.38	1.70	9.50	10.50	2.10	2.66	3.84	0.72	7.77
	2000	7.79	9.01	8.89	0.40	2.00	10.14	13.95	2.49	3.07	4.40	0.92	7.76
	2007	9.90	10.17	10.50	0.44	3.01	13.00	15.00	3.02	3.31	4.74	1.05	7.76
	2014	9.96	11.72	13.34	0.48	3.90	13.60	18.00	3.59	4.05	5.73	1.14	7.76
Average		8.47	9.73	9.96	0.43	2.65	11.56	14.36	2.80	3.27	4.68	0.96	7.76
W_m	1993	7.50	9.01	8.09	0.38	1.90	10.00	13.08	2.46	2.82	4.05	0.97	7.76
	2000	9.10	11.30	10.09	0.40	2.14	13.86	14.89	3.01	3.16	4.52	0.98	7.70
	2007	11.00	14.20	15.70	0.40	3.20	16.70	21.40	4.13	4.42	6.22	1.68	7.65
	2014	11.32	18.42	19.76	0.50	3.75	17.96	28.29	5.04	5.12	7.14	1.94	7.60
Average		9.73	13.23	13.41	0.42	2.75	14.63	19.42	3.66	3.88	5.50	1.39	7.68
W_{mw}	1993	10.20	11.50	11.02	0.40	2.10	14.85	16.17	3.37	3.35	4.78	1.03	7.70
	2000	10.05	17.50	18.00	0.41	2.90	18.50	24.56	4.54	4.85	6.78	1.10	7.60
	2007	18.50	21.45	23.58	0.52	3.80	19.15	41.10	6.40	5.28	7.33	1.83	7.51
	2014	23.00	25.56	27.06	0.58	3.80	25.22	47.18	7.68	5.49	7.61	2.21	7.40
Average		15.44	19.00	19.92	0.48	3.15	19.43	32.25	5.50	4.74	6.64	1.54	7.55
Wn = Nile water				Wm = mixture water					Wmw = marginal waste water				

It was increased by 22.36, 67.89 and 104.88% in 2000, 2007 and 2014, respectively compared to that of 1993 by using W_m in irrigation. The same trend was observed when using the marginal waste water (W_{mw}) in irrigation since the EC_e was increased by 34.72, 89.91 and 127.89% in year 2000, 2007 and 2014, respectively compared to that of 1993. The data also revealed that the soil salinity exceeded the limiting level of EC > 4 dS/m in 2000 and 2007 with using the marginal waste and the mixture water in irrigation, respectively, indicating that the soil become saline. Irrigation with the mixture water mitigated the hazardous effect of using the marginal waste water in irrigation since the soil salinity was reduced by 27.16, 33.70, 35.47 and 41.25% in 1993, 2000, 2007 and 2014, respectively, due to using the mixture water. The EC_e increases are mainly attributed to the original high level of total dissolved salts (TDS) of both mixture and marginal waste waters that accumulate in the soil with continuous application of these waters. Other investigators reported that a slight increase in the soil salinity occurred with the irrigation by the potable water which, of course, was less than that occurred with using the marginal waste water in irrigation (Fatih *et al*., 2007; Atwa *et al*. 2013; Gatta, *et al*., 2015).

The obtained data also showed that concentration of soluble ions increased with using mixture or marginal waste water in irrigation compared to those with using Nile water. Cation concentrations in the soil solution might be arranged in the descending order of Na > Mg > Ca > K. Also, anion concentrations in the soil solution might be ranked in the descending order of SO_4 > Cl > CO_3 + HCO_3. This means that the dominant salts in the soil are magnesium sulfate and sodium chloride. These results are in a harmony with those obtained by Zein *et al*. (2012).

Sodium adsorption ratio (SAR)

Sodium adsorption ratio (SAR) of the soil is also a good index for testing the hazardous effect of using low quality water in irrigation. It had low values for all treatments that ranged between 2.64 and 5.49 (Table 3). Its values increased as the time preceded with using low water quality in irrigation but they are still under the normal limit (SAR < 8) which could be used safely without any restriction. When a soil solution is diluted by a factor X, the reduced ratio $Na/ ((Ca + Mg/ 2))^{0.5}$ will decrease by a factor of $X^{0.5}$. This implies that desodification will always accompany desalinization. Favorable calcium to sodium ratio of the irrigation water and any supply of inherent calcium from the soil is likely to further accelerate the desodification process (Gupta and Abrol, 1990).

Exchangeable sodium percentage (ESP)

Table (3) showed that using these different water types in irrigation resulted in slight increase in the estimated exchangeable sodium percentage (ESP) as the time proceeded. In general, the soil could be considered non sodic one since the ESP value does not exceed the critical limit (ESP < 15). On an average basis, the ESP values were being 4.68, 5.50 and 6.64 when the soil was irrigated by Nile, mixture and marginal waste waters, respectively. Prolonged applications of the marginal waste water (more than 25 years) did not cause a soil sodification since the ESP values in all treatments were less than the critical limit (ESP < 15).

Soil organic matter

All water treatments increased the soil organic matter content with time (Table 3), but it was generally low. This is a natural characteristic of the semi-arid region where the high temperature and dry climate encourage the decomposition of organic matter. Also, the results indicated that the soil organic matter content was relatively higher with using the low quality water in irrigation for a long time than that with using Nile water. The organic matter content in the soil irrigated by the marginal waste water was 1.03% in 1993 and 2.21% in 2014. The comparable soil organic matter values in the respective years due to irrigation with the mixture water were 0.79 and 1.94% and were 0.72 and 1.14% with using Nile water. Friedel *et al*., (2000) reported that using low quality water in irrigation for a long time (after 80 years) increased soil carbon up to 390% compared with those measured in control soils. Also, Mohammad & Mazahreh (2003) and Wang &d Wang (2005) reported that the higher level of wastewater application resulted in a higher level of soil organic matter in the top soil.

Soil Reaction (pH)

Soil pH is one of the most important parameters which reflect the overall change in soil chemical properties. Table (3) also showed that using different water types in irrigation resulted in a slight decrease in the soil pH as the time proceeded. In general, the soil pH could be considered in a range of neutral reaction since the pH values were around 7.0. The continuous irrigation with the marginal waste water for more than 25 years caused a reduction in the soil pH (7.40) compared to those of mixture water (7.60) and Nile water (7.76) in irrigation. The reduction in the soil pH may be attributed to the high content of organic substances and/or high content of ammonium ions in the wastewater that accumulate in the soil. Nitrification of ammonium ions produced from organic matter mineralization would serve as a source of hydrogen ions which may lead to a decrease in the soil pH (Hayes *et al* 1990; Vazquezmontiel *et al*., 1996). Similar results were observed by Mandal *et al*., (2008), who reported that treated waste water could decrease soil pH from 7.66 to 7.55.

Soil macro and micro nutrients.

Table (4) showed that the levels of N, P and K in the soil improved with the loads of marginal waste water being received. On an average basis, the prolonged application of marginal waste water (more than 25 years) resulted in an increase in the total soil nitrogen by 50.00%, soil phosphorus by 30.46% and soil potassium by 50.66% compared to those in the Nile water irrigated soil. The increase in the total soil N, P, and K contents with the marginal waste water application may be attributed to its high contents of these nutrients. Yadav *et al*. (2002) and Mohammad & Mazahreh (2003) reported that the application of wastewater in irrigation resulted in increases in N, P and K of about 4, 10, and 8 times, respectively.

Table 4: Total N, P, K, Fe, Mn and Cu in the soil irrigated with different water types of irrigation water.

Water treatment	Year	N%	Total nutrients (ppm)				
			P	K	Fe	Mn	Cu
Initial	1987	0.07	501.00	520.00	1450.00	570.00	120.00
W_n	1993	0.07	506.00	530.00	1585.00	577.00	122.00
	2000	0.10	551.00	554.00	1683.33	631.00	125.00
	2007	0.10	562.00	603.00	1833.33	650.00	129.00
	2014	0.11	564.00	650.00	1890.00	661.00	132.00
Average		0.10	545.75	584.25	1747.92	629.75	127.00
W_m	1993	0.10	599.00	693.00	1860.00	588.00	133.00
	2000	0.12	634.00	832.00	1966.67	632.00	147.00
	2007	0.13	697.00	903.00	2083.33	653.00	149.00
	2014	0.14	692.00	905.00	2166.67	694.00	167.00
Average		0.12	655.50	833.25	2019.17	641.75	149.00
W_{mw}	1993	0.11	629.00	737.00	2150.00	598.00	143.00
	2000	0.13	674.00	885.00	2233.33	633.00	158.00
	2007	0.16	753.00	939.00	2300.00	673.00	160.00
	2014	0.20	792.00	960.00	2450.00	709.00	178.00
Average		0.15	712.00	880.25	2283.33	653.25	159.75
W_n = Nile water		W_m = mixture water			W_{mw} = marginal waste water		

The results in Table (4) also showed that the micronutrient levels increased as a result of using the marginal waste water in irrigation and as the time proceeded. The soil irrigated by the marginal waste water for a long time caused an increase in micronutrients compared to the soil treated with the mixture water or Nile water. Soil iron, manganese and cupper increased by 29.63, 7.26 and 34.85%, respectively in 2014 when the soil irrigated by marginal waste water compared to those of the soil irrigated by Nile water in this year. Similar results were obtained by Rattan *et al*. (2002) and Rattan *et al*. (2005). They stated that the long-term use of swage waste waters on agricultural lands often results in build-up and elevated levels of these metals in soils.

It might be concluded that the marginal waste water could be mixed with Nile water and used as a safe source for irrigation. The mixture water which might has a reasonable amount of organic matter and colloidal materials could mitigate the hazardous effect resulted from salinity or sodicity appearance. Also, the marginal waste water could be used in irrigation with some precautions, such as leaching the soil once in while by fresh water to get ride of the accumulation salts. Soil amendments, such as gypsum and farmyard manure prevent the negative effect of using the marginal waste water in irrigation.

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