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Impact of Treated Wastewater Irrigation on Soil Chemical Properties and Crop Productivity

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Abstract: The present study was carried out to investigate the impact of treated wastewater on the soil properties, soil fertility and crop productivity. Crops were irrigated with groundwater and secondary treated wastewater. The use of the secondary treated wastewater has shown improvement in the physicochemical properties of the soil, crop yield along with the nutrient status as compared to the application of groundwater. The results showed better crop growth with increased fertility status of the soil. The findings give applicable advice to commercial farmers for proper management and use of domestic wastewater for agricultural purpose. In addition, proper irrigation management and periodic monitoring of soil quality parameters are required to minimize adverse effect on the soil.

Key words: Treated wastewater · Irrigation · Soil Properties · Crops

INTRODUCTION

The population increase has not only increased the fresh water demand but also increased the volume of wastewater generated. Egypt has already made number of leading steps towards integrated management of drainage water as part of the available annual water budget for meeting the increasing demand on freshwater. The drainage water quantity changes with time depending on water use policies and the management of the main supply system. It was found that the volume of drainage water officially reused for irrigation has increased from 2.8 billion cubic meter / year (in 1985) to 5.2 billion cubic meter / year (in 2000) and expected to be 8.3 billion cubic meter / year by the year 2017. It is anticipated in the near future that both industrial and domestic wastewater will be increased thus reclamation and recycling should be considered as integrated components of water resource policy. Treated wastewater appears to be the only water resource that is increasing as other sources are dwindling. Increasing need for water has resulted in the emergence of domestic wastewater application for agriculture and its relative use. Renewable Freshwater Resources of 1000 m^3 per capita per year is a benchmark below which most countries in the arid zone are likely to experience chronic water scarcity sufficient to impede development and harm human health. It is expected in Egypt that by the year 2025 the annual per capita renewable water will be less than 600 m^3. In Egypt several additional factors contribute to the potential for water shortage, among the most serious is water pollution from a variety of industrial, municipal and agricultural sources. In Egypt domestic water use is about 7% of all water use and is expected to rise as the population grows and urbanization continues. Industrial water use is about 5% and is also expected to rise since the industrialization of Egypt is the most promising option for development, while the agricultural water use comprises the largest share about 88% of all water use. At the mean time the potential for developing other renewable sources for freshwater in Egypt is limited.

Rapid industrial developmental activities and increasing population growth had declined the resources day to day throughout the world. Therefore, there is an urgent need to conserve and protect fresh water and to use the water of lower quality for irrigation. Treated or recycled wastewater (RWW) appears to be the only water resource that is increasing as other sources are dwindling. Consequently the reuse of wastewater for agriculture is highly encouraged [1]. The reuse of wastewater for agricultural irrigation purposes reduces the amount of water that needs to be extracted from water resource [2]. It is the potential solution to reduce the freshwater demand for zero water discharge avoiding the pollution load in the receiving sources. It is the necessity of the present era to think about the existing urban wastewater disposal infrastructure, wastewater agriculture practices, quality of water used, the health implications and the level of institutional awareness of wastewater related issued [3].

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Due to ever increasing population huge volume of domestic wastewater is being produced in cities. Indiscriminate disposal of such water is a cause for pollution of air, soil and groundwater supplies. In Egypt, the available amount of wastewater is about 7 billion cubic meter / year and about 50 % of this water has undergone secondary treatment [4]. Cost of treatment of Domestic wastewater for recycling is too high to be generally feasible in developing countries like Egypt. However, such wastewater exerting most of the nutrient load and could be used as irrigation water to certain crops, tree and plants that may lead to increase in agricultural produce and plantation. Wastewater is a valuable source for plant nutrients and organic matter needed for maintaining fertility and productivity of arid soils [5].

Heavy metal uptake by the plants grown in polluted soils (mostly from anthropogenic activities such as wastewater and sewage sludge application) has been extensively studied [6]. It was found by [7] that plants accumulated heavy metals in their shoot (Ni, 13.65; Cr, 19.73; Zn, 21.6 and Cu 14.76 μg g^{-1} dry weight) and root (Ni, 41.4; Cr, 31.6; Zn, 30.2 and Cu 15.85 μg g^{-1} dry weight) these figures are not for field crops but for hyper accumulative species and found in high concentrations after irrigation with undiluted industrial waste water. Use of industrial waste water, in such form, on agricultural lands is not found suitable without proper treatment. It could be injurious to plants growth and may be a potential threat to food web. [8], during a study of wastewater effects on corn, concluded that macro (N, P and K) and micro elements in the wastewater improve growth and yield of maize, while accumulation of heavy metals such as cadmium and lead in corn was more than the standard limits and critical step for animal feeding.

In the agriculture practices, the irrigation water quality is believed to have an effect on the soil characteristics, crops production and management of water [9]. The objectives of this study were to evaluate the fertility and chemical soil characteristics and the possible accumulation of heavy metals in these soils, in response to irrigation of three grain crops with treated wastewater.

MATERIALS AND METHODS

Sampling of Secondary Treated Wastewater and Groundwater: The secondary treated wastewater was collected from Abou Rawash plant, Giza, Egypt. Groundwater was collected from well nearby field. Samples from secondary treated wastewater were collected two times during the study period in pre-sowing and after harvesting field crops and analyzed in the laboratory for their physico-chemical parameters (Table 1). Micronutrients and Heavy metals are also presented in Table 2.

Soil Site Description: Field experiments were carried out at agriculture farm located on Cairo - Alexandria Desert Road. Initial characteristics of soil prior to application of secondary treated wastewater and ground water are presented in Table 3. The experiment was a factorial, completely randomized design with two main treatments of secondary treated wastewater and groundwater.

Table 1: Characteristics of secondary treated wastewater and Ground water used for irrigation.

Characteristic	secondary treated wastewater	Ground water	FAO acceptable level (Pescod 1992)	L.S.D at 5% for irrigation sources
pH	7.9	7.2	6 -9	0.61
EC (dS /m)	2.3	0.8	0.7 - 3.0	1.27
TSS (mg/L)	64	19	50	43.18
TDS (mg/L)	2157	1469	450 - 2000	612.58
COD as O_2 (mg/L)	59	34	200	22.76
BOD5 as O_2 (mg/L)	32	18	60	13.34
NH_4 (mg/L)	18	5	-	-
CO_3 (mg/L)	246	86	-	132.15
HCO_3 (mg/L)	281	92	-	163.14
SO_4 (mg/L)	94	32	-	49.64
CL (mg/L)	112	45	500	53.19
Ca (mg/L)	54	15	400	31.73
Mg (mg/L)	21	9	60	8.35
Na (mg/L)	119	26	200	84.28
K (mg/L)	22	5	-	5.28

Table 2: Concentrations of micronutrient and heavy metals in irrigation water used.

Micronutrients (µg / L)	secondary treated wastewater	Ground water	FAO acceptable level(Pescod 1992)	L.S.D at 5% for irrigation sources
Fe	167	72	< 5000	86.15
Mn	86	23	< 200	51.83
Zn	56	17	< 2000	32.76
Cu	37	18	< 200	17.34
Cd	5	2	< 10	1.94
Co	23	4	< 50	16.38
Ni	7	3	< 200	2.85
Pb	18	8	< 5000	8.67
Cr	13	9	< 100	2.74

Table 3: Soil properties before and after irrigation by secondary treated wastewater and ground water.

		Corn		Soybean		Cowpea		
		After Irrigation by						
Parameters	Before Irrigation	STWW	GW	STWW	GW	STWW	GW	L.S.D at 5% for irrigation source
pH	8.2	7.62	7.47	7.65	7.52	7.68	7.58	0.126
EC (dS/m)	0.34	0.42	0.36	0.49	0.37	0.46	0.41	0.086
Organic matter (%)	0.276	0.465	0.297	0.472	0.335	0.492	0.317	0.129
Total nitrogen (mg / kg)	194	414	237	466	245	435	229	167
Available nitrogen (mg / kg)	45	59	48	67	49	61	42	9.435
Available phosphorus (mg / kg)	13	23	16	26	19	25	18	4.158
Available potassium (mg / kg)	215	265	231	294	242	277	237	29.14
Fe (µg / kg)	7452	9246	8024	9612	8262	9410	8198	974
Mn (µg / kg)	243	267	251	284	268	270	249	13.68
Zn (µg / kg)	413	684	486	715	512	692	504	167.82
Cu (µg / kg)	29	57	42	72	48	67	44	14.865
Cd (µg / kg)	19	20	19	23	18	22	18	5.821
Co (µg / kg)	6	7	5	8	6	5	8	4.112
Ni (µg / kg)	13	11	9	12	11	10	8	2.715
Pb (µg / kg)	49	21	11	23	13	19	12	6.248
Cr (µg / kg)	3	11	7	13	9	10	8	3.523
L.S.D at 5% for crops					18.459			

Each treatment had three replications. Crops like Corn, Soybean and Cowpea, were grown and irrigated with the application of secondary treated wastewater and groundwater. Drip irrigation system was used and plants were irrigated three times a week.

Methods of Analysis for Secondary Treated Wastewater and Groundwater: The pH of the samples was determined using the pH meter, by calibrating the pH meter using the buffer solutions of known pH values. Electrical conductivity (EC) was determined using the Conductivity Meter calibrated with conductivity standard (0.01 m KCl with conductivity 1413 ì S cm^{-1}). Na+ and K+ was estimated using Flame photometer, carbonates and bicarbonates were determined by Alkalinity method and Chlorides of the samples were determined by using argentometric method of precipitation. Concentrations of soluble Ca and Mg were measured using the EDTA (Ethylene Diamine Tertraacetic acid) titration method and Na and K was measured using flame photometer. Phosphorus was determined using OLSEN extraction (0.5 M $NaHCO_3$).

For the analysis of the micronutrient and heavy metals 50 ml sample was taken and 5 ml conc. HNO_3 was added then samples were digested. The digested samples were filtered through Whatman filter paper no. 42 after filtration the volume was made to 50 ml with the de-ionized water. Samples were analyzed on Atomic Absorption Spectrophotometer (AAS) for concentration by using specific cathode lamp. Atomic Absorption Spectrophotometer was calibrated for each element using standard solution of known concentration before sample injection. All the methods for the analysis were followed according to the Standard methods [10].

Soil Sample Collection and Analysis: The composite surface soil sample (0-30 cm) was collected from experimental site prior to the start of the field experiment. After harvest of the crops, treated soil samples were collected, air dried ground to pass through 2 mm sieve and stored in plastic bottles before analysis. The samples were analyzed for different physical and chemical properties as per the standard procedure. The soil pH was estimated by pH meter in the saturation paste 1:1 suspension [11]. In the same suspension electrical conductivity was also measured using conductivity meter (Orion, EA 940 USA). Soil organic carbon was estimated by Walkley-Black method [12], available phosphorous was determined by Olsen's method [13], available potassium estimated by leaching the soil with in ammonium acetate and the determination of potassium by using flame photometer as per the standard method, available nitrogen was estimated by Kjeldhal method. Total Nitrogen was determined using the Kjeldahl procedure [14]. Available micronutrients and heavy metals were estimated as per procedure described by [15].

Crop Samples and Analysis: Dried seeds samples from the different studied crops were ground and retained for micronutrients and heavy metals analysis [16].

Statistical Analysis: Data was subjected to ANOVA using the GenStat-Discovery Edition 3 and LSD at 5 % test separating statistical significant means.

RESULTS AND DISCUSSION

Effect of Irrigation Water on Soil pH and EC after Harvest: The pH of the pre-sowing soil was found to be normal (8.2) which is most desirable in agricultural soil. In field irrigation with secondary treated wastewater and ground water, the pH of soil extract was found to be slightly decreased from 8.2 before sowing to the range of 7.62-7.68 and 7.47- 7.57 after harvesting, respectively (Table 3). The high content of ammonium in the wastewater (Table 1), resulted in its accumulation in the soil. Nitrification of this ammonium would serve as a source of hydrogen ions which may lead to the decrease in the soil pH [17, 18 and 19]. Although this decrease in the soil pH might not persist longer due to the higher buffering capacity of the soil and the soil pH is expected to rise again [18]. The crops would probably benefit from this temporal decrease in soil pH during the growing season. Such decrease in the soil pH would enhance solubility and availability of certain nutrients in soils such as phosphorus, Fe, Mn, Zn and Cu [20 & 21]. Also the decrease in soil pH can increase other heavy metals. Soil pH was also reported to increase following long term wastewater application [22] where this increase may be attributed to the chemistry and high content of basic cations such as Na, Ca and Mg in the wastewater applied for a long period.

Secondary treated wastewater irrigation resulted in significantly higher values for electrical conductivity (EC) of the soil saturation extract compared to soil irrigated with ground water (Table 3). EC of soil before sowing was 0.34 dSm^{-1}, which after harvest with secondary treated wastewater was found to be 0.42-0.49 dSm^{-1} whereas, in irrigation with ground water it was found to be 0.36-0.41dSm^{-1} (Table 3). These results are in harmony with those of [23]. The increase in EC is mainly attributed to the original high level of TDS of the wastewater that would accumulate in the soil with continuous wastewater application. Ground water, unlike wastewater, did not significantly increase the original EC of the soil. Other researchers reported similar increase in the soil EC by wastewater irrigation, [18 & 24], but contrary to our results they observed an increase in the soil EC even by irrigation with potable water which caused a less increase in the soil EC compared to the wastewater irrigated soil [17 & 25].

Effect of Irrigation Water on Fertility Status of Soil after Harvest: The organic carbon of soil irrigated with secondary treated wastewater was increased from 0.276% to 0.465-0.492% range and which is superior to irrigation with ground water (Table 3). This indicates that secondary treated wastewater irrigation helps to improve in fertility status of soil after harvest of summer grain crops. The organic carbon content in secondary treated wastewater irrigated crops like Corn, Soybean; Cowpea resulted superior than ground water irrigation as presented in Table 3. Organic carbon content of secondary treated wastewater fed soils were found to be higher (0.465-0.492%) than those of ground water irrigated soils (0.297-0.335%) and this is possible due to incorporation of organic matter through secondary treated wastewater. Some researchers reported an increase in the soil organic matter following wastewater irrigation [17, 23 & 25]. The effect of irrigation water on fertility status of soil after harvest of grain crops was significant for available N, P and K (Table 3). The crops irrigated with secondary treated wastewater, recorded significantly higher available N, P and K as compared to crops irrigated with ground water (Table 3). This indicates that secondary treated wastewater irrigation provides the essential nutrients to the crops. It has been noted that secondary treated wastewater improves fertility levels of soil as reported by [23 & 26].

Effect of Irrigation Water on Micronutrient (Heavy Metal) of Soil after Harvest: The experiments showed significant improvement in fertility status of soil with respect to micronutrient as recorded after harvest of crops (Table 3). The improvement might be due to irrigation with secondary treated wastewater in all the crops. The DTPA (Di-ethylene tri-amine penta-acetic acid) extractable consisting Fe, Mn, Zn, Cu, Pb, Co, Cr, Ni and Cd of secondary treated wastewater after harvest were significantly higher than those of ground water. The findings were in conformity with the earlier studies reported by [23 & 27].

Although the wastewater contained small amount of micronutrients, the DTPA extractable Fe and Mn significantly increased in the soil. This could be attributed to the chelation reactions of Fe and Mn with the organic compounds provided by wastewater application, which is considered one of the main mechanisms for enhancing solubility and availability of Fe and Mn in alkaline soils [20]. In addition, both Fe and Mn are transitional metals that can easily change their oxidation states. The possible reducing conditions created during irrigation periods with wastewater can facilitate reduction of both Fe and Mn into the more soluble and available reduced forms. An evidence of reducing condition created by wastewater application can be considered through the enhanced denitrification with wastewater application observed by [17 & 22]. Also pH reduction due to irrigation with wastewater may share in heavy metal availability.

It should be mention that the improper (such as over irrigation) application and/or long term application of wastewater may lead to nutrient imbalance, toxicity problems by heavy metals and soil deterioration or reduction on the soil productivity. Therefore, periodic monitoring of their concentrations in the soil is highly recommended because of the possible accumulation in the soil after continuous wastewater application. In addition, the possible increase in the solubility of the indigenous insoluble heavy metals in the soil as a result of the chelation or acidification action of the applied wastewater irrigation has also been reported [28].

Effect of Irrigated Water on Crop Yield and Quality of Crops: The use of secondary treated wastewater has favorably influenced the crop production; its continuous application for number of years may result in enrichment in top soils [29 & 30]. The crops yield irrigated with secondary treated wastewater was found to be better as compared to those irrigated with ground water. The test weight of corn, soybean and cowpea was significantly higher as recorded by secondary treated wastewater over the ground water irrigation. The crop yield of grain was significantly influenced due to irrigation of crops through different sources (Table 4). The significantly higher grain yield was recorded due to application of secondary treated wastewater over ground water irrigation. The secondary treated wastewater contains large amount of nutrients and therefore could be used as a source of irrigation [31] as evident by the results of [23, 32 & 33]. Also the analysis of wastewater (Table 1) indicated that its fertilizer value was greater than the groundwater. Amongst the crops irrigated with secondary treated wastewater, corn recorded highest grain yield, followed

Table 4: Effect of secondary treated waste water and Ground water irrigation on Crop yield and quality after harvest.

Irrigation source	Weight of 100 seeds (g)	Grain yield (Kg / Acre)
Corn		
STWW	23.15 a	3125
GW	21.24 b	2845
Soybean		
STWW	21.74 a	1186
GW	19.92 b	964
Cowpea		
STWW	22.68 a	850
GW	20.43 b	742
L.S.D at 5 % for irrigation source	-	156.45
L.S.D at 5 % for crops	-	364.915

Table 5: Average concentrations of Micronutrients and Heavy metals after harvesting the crops for water resources.

	Corn		Soybean		Cowpea	
Concentration of Micronutrients (μg/kg)	STWW	GW	STWW	GW	STWW	GW
Fe	5.2	3.4	4.7	3.6	4.9	3.1
Mn	7.6	2.1	6.8	2.3	7.2	2.4
Zn	11.0	6.0	10.5	5.0	10.2	6.0
Cu	0.54	0.35	0.68	0.32	0.62	0.34
Cd	0.23	0.19	0.26	0.21	0.25	0.20
Co	ND	ND	ND	ND	ND	ND
Ni	ND	ND	ND	ND	ND	ND
Pb	3.6	0.52	3.4	0.55	3.5	0.53
Cr	ND	ND	ND	ND	ND	ND
L.S.D at 5 % for crops				0.114		

ND: Not detected

by soybean. The lowest grain yield was recorded in cowpea. The interaction effect of sources of irrigation and crops were resulted in significant effects on grain yield. The most significantly grain yield of crops was recorded due to application of wastewater. Similar results were also recorded by [34 & 35].

Micronutrients in Crops: The high concentration of micronutrients in soils and wastewater was reflected by higher concentrations of metals in different crops. The results indicated the highest amount of micronutrients in crops irrigated with secondary treated wastewater was (Fe, Zn, Mn, Cu, Pb) as shown in Table 5. These results show that the use of treated wastewater in agricultural lands enriched soils with heavy metals to concentrations that may cause soil, groundwater pollution and health risks on human and plant in the long-term.

CONCLUSIONS

Use of secondary treated wastewater for irrigation should be regarded as valuable source for agriculture than discarding. Using of secondary treated wastewater could increase water resources for irrigation and may prove to be beneficial for agricultural production. Proper management of wastewater irrigation and periodic monitoring of soil fertility and quality parameters are required to ensure successful, safe and long term reuse of waste water for irrigation.

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