Effects of Treated Wastewater Irrigation on Uptake of Essential Nutrients, Absorption of Heavy Metals and Yield Characters of Cucumber (*Cucumis Sativus*)

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ABSTRACT

This study aims to evaluate the effect of tertiary treated wastewater (TW) irrigation on uptake of macro- (i.e., N, P, K, Ca and Mg), micro- (i.e., Cu, Fe, Mn and Zn) nutrients, and heavy metals (i.e., Cd, Ni and Co) and yield characteristics of cucumber (*Cucumis sativus.*) plant. The experiment was conducted in a greenhouse under controlled conditions. Plants were grown in plastic pots filled with a sandy soil and irrigated with either TW or ground water (GW). Each treatment was replicated six times. The obtained data showed that irrigation with TW caused significant increases in the contents of leaves of N, P and K (3.12, 0.78, 4.35, 2.27 and 0.48%, respectively), and Cu, Fe, Mn and Zn (6.97, 97.70, 21.50 and 23.08 mg kg^{-1}, respectively) as compared to GW irrigation. The contents of these nutrients in fruits showed similar trend observed in leaves. Heavy metals (Cd, Ni, and Co in leaves were respectively 0.37, 0.64 and 0.71 mg kg^{-1} for TW compared to 0.35, 0.51 and 0.63 mg kg^{-1} for GW. In fruits, they were 0.14, 0.18 and 0.16 mg kg^{-1} for TW and 0.12, 0.15 and 0.11 mg kg^{-1} for GW, respectively. Irrigation with TW resulted in significantly higher total number of fruits/plant (57.20), chlorophyll contents (25.50), plant height (109.20 cm) and yield (4.58 kg $plant^{-1}$) than irrigation with GW. It could be concluded that the TW can be used as an alternative safe water source for irrigation taking into considerations its stimulating effects on plant uptake of essential nutrients. Frequent monitoring of its impacts on absorption of heavy metals by growing plants is cautiously suggested to avoid future consequences on a long-term basis.

Key words:
Macronutrients, micronutrients, heavy metals, wastewater and groundwater.

INTRODUCTION

Reuse of treated wastewater for irrigation in agriculture has expanded during the last two decades (Hamoda, 1996; Blumenthal et al., 2000). Smit and Nasr (1992) indicated that at least 10% of world's population is thought to consume foods produced by irrigation with wastewater. Also, it has been estimated that at least 20 X 10^6 ha in 50 countries are irrigated with raw or partially treated wastewater (Hussain, et al., 2001; van der Hoek, 2004). Different studies, however, suggested that treated effluent can be used for irrigation under controlled conditions to minimize pathogenic and toxic contaminations for agricultural products, soils, surface and ground water (Mahasneh, et al., 1989, FAO, 1997).

Badr (1984) indicated that treated wastewater makes a valuable contribution to the scarce water resources in the Kingdom of Saudi Arabia. Most of the reused wastewater in the Kingdom is tertiary treated waters. This type of treatment is an efficient procedure in improving the quality of the produced wastewater. Hamoda, et al. (2004) illustrated that tertiary treatments significantly improved quality criteria of wastewater (i.e., up to 95-99%).

Treated wastewater is considered as an important source of plant nutrients for soils particularly poor in fertility (Jimenez-Cisneros, 1995; Angin, et al., 2005). Different studies suggested that the use of wastewater as a supplemental irrigation water provides several plant nutrients, enhances crop production and increases water and nitrogen use efficiencies (KACST, 1992; Hussain and A1-Saati, 1999; Al-Dervasi, 2002). Hussain and A1-Saati (1999) showed that irrigating with treated wastewater caused a save of up to 50% of applied inorganic nitrogen fertilizer when such water contains 40 mg N L^{-1}.

In an experiment conducted for two seasons under field and greenhouse conditions, KACST (1992) validated that various crops (i.e., alfalfa and tomato) irrigated with treated wastewater had significant increases in yields and yield components (such as plant height, stem diameter and fresh and dry weights). Al-Shanghiti and Shammas (1985) found that irrigating with wastewater provided some nutrients to the grown crops reducing the quantities of applied fertilizers. Neilsen, et al. (1989) observed that N added by irrigation with wastewater increased numbers of apple fruits and yield after the 3 years experiment of a zero N application. They indicated that P in wastewater played a significant role in the establishment of early growth and yield of young apple trees. The plant nutrients in wastewater are capable of improving crop growth and yield (Cordonnier and Johnston, 1983; Saenz, 1987; Kiziloglu, et al., 2008). This study aims to evaluate the effects of tertiary treated wastewater irrigation on cucumber yield and its components and the absorption of essential macro- and micro-nutrients and heavy metals by cucumber plants grown in sandy soil under greenhouse conditions.

MATERIALS AND METHODS

The current study was conducted in a greenhouse at the Agricultural and Veterinary Training and Research Station (AVTRS), King Faisal University (KFU) in 2007/2008. Two different sources of irrigation water were used in the experiment: (i) tertiary treated wastewater (TW) and (ii) groundwater (GW)). The GW (i.e., the control) was obtained from an artisan well of Um-Rrudhmma (UER) aquifer whilst the TW was brought from Al-Hofuf Wastewater Treatment Plant (HWWP). The criteria of both waters were analyzed by Page *et al*,(1982) and summarized in table 1. The layout of the experimental was a randomized complete design with six replicates, giving a total of 12 experimental units.

Table 1: Criteria of both irrigation waters used in the experiment.

Parameters		Unit	Groundwater (GW)	Treated water (TW)
pH			7.2	7.5
EC		dS m^{-1}	1.9	1.7
cations	Na^+	mg L^{-1}	167.9	151.8
	K^+		31.2	15.4
	Ca^{2+}		214.2	73.4
	Mg^{2+}		63.2	41.3
anions	CO_3^{2-} + HCO_3^-	mg L^{-1}	323.3	226.9
	Cl^-		299.9	262.3
	SO_4^{2-}		449.1	309.1
	NO_3^-		2.4	21.2
micronutrients	Fe	mg L^{-1}	0.31	0.52
	Mn		0.1	0.07
	Cu		0.02	0.004
	Zn		0.04	0.05
Heavy metals	Cd	mg L^{-1}	Nd*	0.001
	Co		Nd	0.004
	Ni		Nd	0.005

*Nd: not determined

Cucumber plants (*Cucumis sativus*; jasmine spp.) were grown in plastic barrels (i.e., pots) of 42 cm top and 38 cm bottom diameters with 60 cm height. Each barrel has three holes at the bottom for drainage purposes (Figure 1). The barrels were used to avoid any contamination that might happen to the permanent soil of the greenhouse. All barrels were uniformly filled in with a sandy soil. The chemical and physical properties of the soil were analyzed as Page *et al* (1982) and outlined in table 2. The barrels were laid out into two rows. The first row was designated for the TW treatment and the second was for the GW treatment. All six replicates were randomly distributed within each row. Drip irrigation system was applied in the experiment. The irrigation interval was every other day to maintain the soil moisture at 75% of the field capacity. The recommended quantity of irrigation water was applied (Ministry of Agriculture, 2007). All other farming practices were also implemented in accordance to the MAW recommendations.

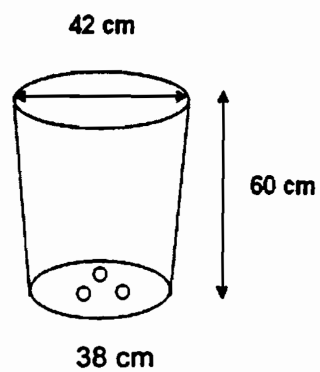

Figure 1: The general design of the plastic barrels used in the experiment.

Table 2: Main physical and chemical properties of the soil used in the experiment.

Parameter	Value	Parameter	Value
EC (dS m^{-1})	1.12	Sand (%)	92.32
pH	7.11	Silt (%)	2
Na^{+} (mg L^{-1})	34.58	Clay (%)	5.68
K^{+} (mg L^{-1})	28.15	Textural class	Sand
Ca^{2+} (mg L^{-1})	110.42	Organic matter (%)	0.12
Mg^{2+} (mg L^{-1})	39.76	CaCO3 (%)	2.6
CO_3^{2-}+HCO_3^{-} (mg L^{-1})	70.27	Saturation percentage (%)	24.5
Cl^{-} (mg L^{-1})	202.83	Field capacity (%)	12.20
SO_4^{2-} (mg L^{-1})	126.92	Permanent wilting point (%)	6.11
NO_3^{-} (mg L^{-1})	17.36	Available water (%)	6.09
Total N (%)	0.04	Cd (mg L^{-1})	0.013
Fe (mg L^{-1})	0.01	Co (mg L^{-1})	0.011
Mn (mg L^{-1})	1.05	Ni (mg L^{-1})	0.042
Zn (mg L^{-1})	0.12		
Cu (mg L^{-1})	0.01		

Planting and plant sampling:

Two seedlings of 14 days old cucumber seedlings were transplanted into each barrel. The transplant was on 9/12/2007. Harvesting of plants started from the beginning of February 2008 for two months (i.e., April 2008). During the first harvesting four weeks, fruits were collected twice a week, after which they were collected three times a week (i.e., during the peek of growth). Number of fruits and weight (kg) of harvested fruits per plant were determined. For each treatment, the average harvested fruit of the number and weight per plant were calculated. The total yield (kg $plant^{-1}$) was also calculated. In addition, plant height (cm) was measured using a rolling meter after seizing the experiment. The chlorophyll contents in the 4^{th} leaf from the top of each plant were also determined using a chlorophyll meter (SPAD-502 model). This was done after 50 days from seedling transplantations.

Plant analysis:

For each treatment, samples of both leaves and fruits were separately collected from each plant (i.e., replicate). They were washed with deionezed water, oven dried at 65C° for 48 hours and then grinded with a mill grinder. They were then stored in a plastic bag in a refrigerator at 4°C for the upcoming chemical analyses. Total Kjeldahl N (TKN) was determined using a micro Kjeldahl procedure with sulfuric acid H_2SO_4 and digestion catalyst (Page, et al., 1982). Another sample were digested by nitric acid-hydrogen peroxide procedure for the determination of total contents of the macro-nutrients (i.e., phosphorus (P) and potassium (K)), the micro-nutrients (i.e., zinc (Zn), iron (Fe), cupper (Cu) and manganese (Mn)) and the heavy metals (i.e., nickel (Ni), cadmium (Cd) and cobalt (Co)). The determinations of these elements were done using an atomic absorption spectro-photometer (AAS) and inductively coupled plasma atomic emission spectrometry (ICP-AES) (Page, et al., 1982). All chemical analyses were completed in the laboratories of the Agricultural Environment and Natural Resources Department, College of Agricultural and Foods Sciences, King Faisal University.

Statistical analysis:

The obtained data were statistically analyzed using a computer program by the Statistical Analysis System Institute (SAS Institute, 2000). The value of least significant difference at 5% levels ($LSD_{5\%}$) between the averages of treatments were also calculated by Duncan Multiple Range Test (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION:

Nutrients content in plant

Table (3) includes the data of total macronutrient contents (N, P and K) in leaves and fruits of cucumber plants as affected by the irrigation water qualities. The results showed that the concentrations of these macronutrients, in both plant parts, were significantly higher under TW irrigation than under GW irrigation and were generally higher in the leaves than in the fruits. In both plant parts, the contents of these nutrients were in a descending order of K > N > P. The contents of both P and K in leaves were within the sufficient levels, yet N was deficient as reported by Jones (1998) since concentrations of N, P and K as sufficient levels in the range: 4.5-6.0%, 0.34-0.75% and 3.9-5.0%, respectively, for the cucumber plants.

Table (3): Total macronutrient contents in leaves and fruits of cucumber plants (%) as affected by irrigation water qualities.

Irrigation water quality	Plant parts	N	P	K
Tertiary treated water (TW)	Leaves	3.12 (±0.40)	0.78 (±0.04)	4.35 (±0.16)
Groundwater (GW)		2.55 (±0.40)	0.74 (±0.04)	4.03 (±0.03)
$LSD_{5\%}$		0.51	o.o1	0.14
Tertiary treated water (TW)	Fruits	1.56 (±0.02)	0.44 (±0.02)	1.70 (±0.19)
Groundwater (GW)		1.14 (±0.03)	0.41 (±0.01)	1.38 (±0.13)
$LSD_{5\%}$		0.04	0.02	0.31

* Numbers between parentheses refer to standard deviation.

The data of micronutrients contents (Cu, Fe, Mn and Zn) in both leaves and fruits are summarized in Table 4. These data showed that the contents of these elements are significantly higher in plants irrigated with TW than in plants irrigated with GW. They are also higher contents in leaves than in fruits. The concentrations of these elements are in an order of Fe > Zn > Mn > Cu. The data obtained also showed that Cu and Zn are at the lower limits of the sufficient levels for cucumber plants, whilst both Fe and Mn are less than those levels (Jones, 1998). The suggested sufficient levels of these micro-elements in the leaves of cucumber plants are 5-30 mg Cu kg^{-1}, 100-500 mg Fe kg^{-1}, 20-300 mg Mn kg^{-1} and 25-100 mg Zn kg^{-1} (Jones, 1998).

Table (4): Total micronutrient contents in leaves and fruits of cucumber plants (mg kg^{-1}) as affected by irrigation water qualities.

Irrigation water quality	Plant parts	Cu	Fe	Mn	Zn
Tertiary treated water (TW)	Leaves	6.97 (±1.05)	97.70 (±1.77)	21.50 (±1.04)	23.08 (±1.03)
Groundwater (GW)		5.16 (±0.93)	86.20 (±4.70)	19.87 (±0.40)	20.80 (±1.3)
$LSD_{5\%}$		1.47	5.72	1.46	1.22
Tertiary treated water (TW)	Fruits	5.21 (±0.10)	38.03 (±3.8)	9.50 (±0.52)	8.00 (±0.26)
Groundwater (GW)		4.96 (±0.10)	29.22 (±6.72)	7.23 (±0.76)	7.26 (±0.12)
$LSD_{5\%}$		0.04	6.65	1.22	0.14

* Numbers between parentheses refer to standard deviation.

The increases in cucumber plant contents of essential macro- and micro-nutrients under TW irrigation is possibly explained by the contributing ability of such water in providing these nutrients. Similar results were also observed by other investigators that reveled plant essential nutrients were significantly higher in plants irrigated with treated wastewater than those irrigated with groundwater or ordinary irrigation water (Al-Shanghiti and Shammas, 1985; Jimenez-Cisneros, 1995; Angin, et al., 2005; Rusan, et al., 2007; Kiziloglu, et al., 2008; Al-Derfasi, 2009). Husaain and Al-Saati (1999) suggested that irrigating with treated wastewater leads to save 50% of applied mineral N fertilizers using wastewater containing 40 mg N L^{-1}.

Heavy metals contents in plant

The data of the total contents of heavy metals (Cd, Ni and Co) in both leaves and fruits of cucumber plants (mg kg^{-1}) as affected by irrigation water quality are presented in Table 5. The data show that the levels of these metals are significantly higher, in both parts of the plants, irrigated with TW than those irrigated with GW. The data also revealed that these metals are in an order of Co > Ni > Cd under both water qualities. It seems from the obtained data that the concentrations of these data are relatively low. However, it is worthy to indicate that they may cause serious impacts on environment on a long term basis, considering their ability to accumulate in the surrounding natural resources, particularly soils. Various investigators indicated that irrigation with treated wastewater causes noticeable increases in the levels of heavy metals on a long term basis (Mapanda, et al., 2005; Rattan, et al., 2005). This suggests that regular monitoring of these heavy metals in the natural resources is inevitably advised.

Table (5): Total contents of heavy metals in leaves and fruits of cucumber plants (mg kg^{-1}) as affected by irrigation water qualities.

Water quality	Plant parts	Cd	Ni	Co
Tertiary treated water (TW)	Leaves	0.37 (±0.01)	0.64 (±0.03)	0.71 (±0.02)
Groundwater (GW)		0.35 (±0.02)	0.51 (±0.10)	0.63 (±0.04)
$LSD_{5\%}$		0.01	0.12	0.06
Tertiary treated water (TW)	Fruits	0.14 (±0.01)	0.18 (±0.01)	0.16 (±0.01)
Groundwater (GW)		0.12 (±0.01)	0.15 (±0.01)	0.11 (±0.01)
$LSD_{5\%}$		0.018	0.014	0.010

* Numbers between parentheses refer to standard deviation.

Yield and yield components:

Data of plant height (cm) and chlorophyll contents are summarized in Table 6. It is clear that irrigating with the TW significantly increased plant height compared with GW irrigation. Also, the chlorophyll contents in the plants irrigated with TW were significantly higher than those irrigated with GW. Such improvements in yield components resulted in significant increases in yield values of both number of fruits and total yield per plant (Figures 2a & b, respectively). Both yield characters showed that TW irrigation caused significantly higher yield than GW irrigation, resulting in at least 20% increases. These results imply the effects of TW irrigation on such parameters of plant yield and yield components. KACST (1992) suggested that treated wastewater irrigation enhanced plant growth parameters resulting in better yield for both tomato and alfalfa crops grown under greenhouse and field conditions, respectively.

Table (6): Plant height and chlorophyll contents of the cucumber plants as affected by irrigation water qualities.

Parameters	Groundwater (GW)	Tertiary treated wastewater (TW)	$LSD_{5\%}$
plant height (cm)	95.9 (±2.5)	109.2 (±1.8)	4.10
Chlorophyll contents	22.5 (±0.5)	25.5 (±0.8)	0.97

* Numbers between parentheses refer to standard deviation.

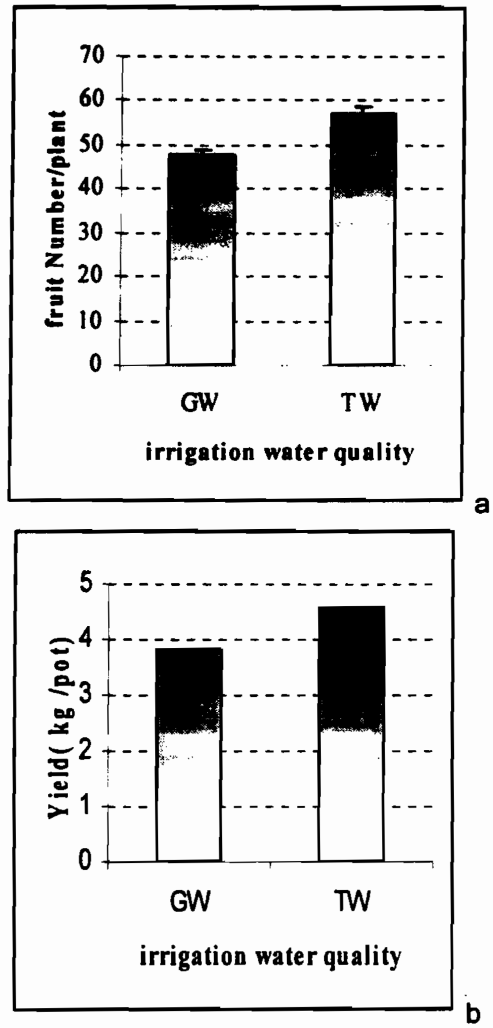

Figure 2: Number of fruits per plant (a) and total yield (kg plant^{-1}) (b) of cucumber plants as affected by irrigation water qualities (Bars on each column refer to standard deviation values).

CONCLUSIONS

It may be concluded from the results of this study that tertiary treated wastewater (TW) can be used safely as an alternative sources for irrigation.

It is a valuable water resource that might be considered in any future solution to overcome the scarce water problems in the arid and semi-arid regions. Its stimulating effects on plant uptake of essential macro- and micro-nutrients should be also taken into considerations. However, frequent monitoring of its quality and impacts on absorption of heavy metals by growing plants are critically encouraged to avoid any unwelcoming contamination consequence on a long-term basis.

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الملخص العربى

تأثيرات الري بمياه الصرف الصحي المعالجة على امتصاص العناصر الغذائية الأساسية و الثقيلة و صفات الإنتاج لمحصول الخيار

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تهدف هذه الدراسة إلى تقويم تأثيرات الري بمياه الصرف الصحي المعالجه على امتصاص العناصر الغذائية الأساسية الكبرى (N, P, K, Ca & Mg) و الصغرى (Cu, Fe, Mn & Zn) و العناصر الثقيلة (Cd, Ni & Co) و صفات الإنتاج لنبات الخيار (*Cucumis sativus*) صنف (jasmine. أجريت هذه التجربة تحت ظروف محكمة داخل البيت المحمي. استزرع نبات الخيار في أصص بلاستيكية مملوءة بتربة رملية و التي تم ريها إما بمياه صرف صحي معالجة (TW) أو مياه جوفية (GW، شاهد)، مع تكرار كل معاملة 6 مرات. أظهرت النتائج المتحصل عليها أن الري بمياه TW زاد معنوياً محتوى الأوراق من عناصر ن و فو وبو الغذائية الكبرى (,3.12, 0.78, 4.35 2.27 & 0.48%، على التوالي) وعناصر الصغرى ($6.97, 97.70, 21.50 \& 23.08\ mg\ kg^{-1}$، على التوالي) مقارنة بالري بمياه GW. كان التغير في قيم هذه العناصر في الثمار على نفس النمط المشاهد في الأوراق. كانت قيم محتوى الأوراق من العناصر الثقيلة الكادميوم و النيكل و الكوبالت 0.37، 0.64 و 0.71 ملجم كجم$^{-1}$ لمعاملة الري بمياه TW مقارنة بالقيم 0.35، 0.51 و 0.63 ملجم كجم-1 لمعاملة الري بمياه GW. كما كانت هذه القيم في الثمار على نحو 0.14، 0.18 و 0.16 بمياه TW و 0.12، 0. 15 و 0.11 بمياه GW، على التوالي. وقد نتج عن الري بمياه TW زيادة معنوية في العدد الإجمالي للثمار لكل نبات (57.20)، محتويات الكلوروفيل فى الأوراق (25.50)، طول النبات (109.20 سم) و الإنتاج الكلي (4.58 كجم للنبات) مقارنة بالري بمياه GW. يستنتج مما سبق إمكانية استخدام المياه المعالجة ثلاثياً (TW) كمصدر بديل و آمن لأغراض الري مع الأخذ في الاعتبار تأثيره التحفيزي لامتصاص العناصر الغذائية الأساسية. و يتحتم التأكيد على ضرورة المراقبة الدورية لتأثيرات هذه المياه المعالجة على امتصاص العناصر الثقيلة بواسطة النبات النامي لتجنب أي تبعات مستقبلية على المدى البعيد.

كلمات دالة: العناصر الغذائية الكبرى / العناصر الغذائية الصغرى / العناصر الثقيلة / المياه العادمة / الماء الجوفي والخيار.