Impact of wastewater irrigation on the yield and quality of white radish under arid environment

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Abstract: Field experiments were carried out over two consecutive seasons (2011 and 2012) at an agricultural site in the western region of Saudi Arabia, to study the effect of wastewater irrigation on the yield, toxic metals, and fecal coliform bacteria of white radish crop. Six different wastewater qualities were prepared by diluting various percentages of the treatment plant's effluent with local groundwater (LGW). The crop water requirement for white radish was calculated by Penman-Monteith equation for dry land condition and supplied daily by two drip irrigation systems; surface and subsurface. Root yield, irrigation water use efficiency (IWUE), fecal coliform, and content of toxic metals in the plant and soil were determined at the end of each growing season. Results indicated that the highest root yield/ha, and IWUE were obtained from the treatments of 60T (60% wastewater mixed with 40% LGW) and 100T (100% wastewater). Due to the relatively early cultivation in the second growing season, the total yield/ ha and IWUE were higher than that of the first season.On the other hand, fecal coliform bacteria count and toxic metals increased systematically in the plant and soil as the quantity of wastewater in the irrigation water increased. Notably, the concentrations of toxic metals in the plant and soil were less than that of the cytotoxic standards declared by WHO-FAO (2007) and EU (2002). In conclusion, the best treatments that produced the highest yield and IWUE with minimal microbial contamination were 60T and 100T suggesting a safer use, better performance and considerable LGW conservation.
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1. Introduction

Agricultural irrigation with treated wastewater is becoming a common and rapidly increasing practice in arid and semi-arid regions. Many researchers have discussed the process of reusing wastewater in agriculture **(Hamilton et al., 2007; Das and Kumar, 2009). Abdel-Magid (1996)** tested the suitability of wastewater effluent from a treatment plant at Unayzah in the central region of Saudi Arabia for reuse in irrigation and found that the phytochemical analysis tests of the treated effluent quality parameters fell within local and international standards for restricted and unrestricted irrigation reuse. In addition, the total coliform count was high, thereby representing an unacceptable use of effluent in unrestricted irrigation. In another study by **Arafa et al. (2001)**, staphylococcus, coliform, and fecal coliform bacteria in the wastewater were evaluated in the city of Makkah, Saudi Arabia and found acceptable for restricted reuse in agriculture.

Wastewater effluent can be used for growing various field and vegetable crops since it increases the fresh and dry weight, yield, content of nitrogen and phosphorus as well as many other nutrient elements **(Akponikpe et al., 2011)**. **Cordonnier and Johnston (1980)** used secondary treated municipal wastewater and well water to irrigate soybean fields, and found that the wastewater treatment yielded 354 and 205 kg/ha more than the control and well water, respectively. **Al-Abdulqader and Al-Jaloud (2003)** found that irrigating wheat and alfalfa with wastewater increased their yield by approximately 11% and 23%, respectively. Many researchers **(Kouraa et al., 2002; Munir and Mohammed, 2004; Lopez et al., 2006; Jasim and Abdul, 2010)** have used wastewater in growing corn, potato, lettuce, olive trees, and alfalfa. Results from these studies indicated an increase in production as compared to those crops irrigated with natural water resources. **Al-Lahham et al. (2003)** studied the effect of wastewater diluted with different percentages of potable water in the production of tomato. Results showed an increase in production as wastewater percentage increased. **Zavadil (2009)** reported that primary-treated wastewater increased the yield of all vegetable crops, with the increase being statistically significant in most cases. Application of municipal wastewater for various vegetable crops significantly increased total chlorophyll and carotene content, established good growth, and increased biomass and yield **(Singh and Agrawal, 2009; Khan et al., 2010; Thapliyal et al., 2011; Heidari 2012). Tamoutsidis et al., (2002)** found that the yield of some vegetable crops such as lettuce, endive, spinach, and radish was decreased by increasing the dose of municipal wastewater in irrigation water.

Vegetables accumulate heavy metals in their edible and non edible parts **(Gupta et al., 2010; Sinha et al., 2006).** Heavy metals such as Zn, Mn, Ni, and Cu act as micro-nutrients at lower concentrations, these become toxic at higher concentrations. Root crops such as potato, carrot, turnip, and radish generally accumulate less pollutant elements than leafy vegetables **(Hundal and Arora, 1993)**. Leafy vegetables grown in soils contaminated with heavy metals accumulate higher amounts of metals than those grown in uncontaminated soils because they absorb these metals through their leaves **(Al Jassir et al., 2005).** Irrigation with contaminated wastewater increases the concentration of Cu, Fe, Mn, Zn, Al, Cr, and Ni in soils, potato leaves, and potato tubers. However, the increase of heavy metal concentrations in plants is less than the concentrations of heavy metals in soils **(Brar et al., 2000). Rattan et al. (2005)** indicated that the accumulation of dread metals like Cd and Pb did not pose any threat, even after long-term use of sewage effluents. As far as heavy metal contents are concerned, leafy green vegetables grown in sewage-irrigated soils are still safe for human consumption. Plant Pb and Cd increase with wastewater irrigation and their levels become higher with longer periods of wastewater application **(Rusan et al., 2007).** Lettuce and radish were found to be safer than other vegetables in terms of the accumulation of heavy metals in humans through the edible portion **(Intawongse and Dean, 2006).**

Drip irrigation is used worldwide and has proved successful in using water resources efficiently to produce vegetable crops **(Locascio, 2005).** The major benefits of drip irrigation include its ability to apply low volumes of water to plant roots, reduce evaporation losses, and improve irrigation efficiency **(Schwankl et al., 1996)**. Subsurface drip irrigation, which applies water below the soil surface by using buried drip tapes **(ASAE, 2001),** has many benefits over conventional drip irrigation **(Singh and Rajput, 2007).** Biophysical advantages include lower canopy humidity and fewer diseases and weeds **(Camp and Lamm, 2003).** The yield and quality of vegetable crops can improve more significantly with a buried drip system compared to a surface drip system **(Phene et al., 1987; Bar-Yosef, 1989).** Environmental benefits include the ability to manage nutrient and pesticide leaching and the threat to groundwater **(Lamm, 2002).**

Heidarpour et al. (2007) and **Mollahoseime (2013)** compared the surface irrigation method with the subsurface irrigation method to study the effects of treated wastewater on soil contamination. Results indicated that subsurface irrigation increased soil EC, Na, and Mg as compared to surface irrigation. **Oron et al. (1995)** examined poliovirus penetration into tomato plants under subsurface drip irrigation using secondary treated wastewater. Results showed a limited penetration into the plant through the roots. Furthermore, no virus contamination was found in the leaves of the plant irrigated with wastewater spiked with viruses, while a limited amount of virus contamination was detected in leaves of plants irrigated with tap water enriched with poliovirus.

Most wastewater environmental studies in the western region of Saudi Arabia have focused on the impact of wastewater disposal in the marine environment. However, few studies have been conducted on the utilization of wastewater in irrigation agriculture, especially for vegetable crops. The objectives of this work are as follows: first, investigate the effect of irrigation with diluted wastewater on the yield and yield components of white radish; second, evaluate the microbial and toxic element pollution under the surface and subsurface irrigation systems and different wastewater treatments; and third, quantify the accumulation of toxic metals in the soil.

2. Materials and methods

2.1 Experimental design

Experiments were carried out during the two successive seasons of 2011 and 2012 at the Agricultural Experimental Research Station of King Abdulaziz University (KAU), located at Hada Al-Sham village which is 110 km northeast of Jeddah city, Saudi Arabia. The soil was classified as sandy loam. Initial soil analyses of the experimental site before cultivation are presented in Table 1. The white radish crop was cultivated in a split-split plot design with four replicates and a plot size of 2x3 m. The main plot treatments contained six wastewater qualities each equipped with surface and subsurface drip irrigation systems. Bani-Malik Wastewater Treatment Plant (WWTP) is one of nine typical WWTP in Jeddah city and was used as the wastewater source in all experiments. The plant receives and treats raw wastewater from neighboring districts up until the secondary stage. The effluent is mainly utilized by municipalities in irrigating the public gardens of Jeddah city. Trucks were used to convey the effluent to the field site where it was received in two large reservoirs. Both reservoirs were connected to six different storage tanks which constituted six different wastewater treatments, namely LGW, 20T, 40T, 60T, 80T, and 100T. These wastewater treatments were prepared by mixing a pre-specified percentage of Bani-Malik WWTP effluent with local groundwater (LGW) source. For example, 20T indicates 20% wastewater mixed with 80% local groundwater; that is, the LGW which represents the control quality contains no effluent and the 100T is primarily a 100% effluent. Each treatment was investigated under the two irrigation systems. Table 2 presents the initial toxic metal concentrations and biological characteristics of LGW, influent and effluent of Bani-Malik WWTP, along with the standards of the Ministry of Water and Electricity **(MWE, 2005)** as well as **FAO (1985).**

Table 1. Initial soil analysis of the experimental site before cultivation.

Parameter		Concentrations
pH		7.9
EC (Electrical Conductivity) dS/m		2.4
Organic Matter (OM) %		0.55
Toxic metals mg/kg	Pb	0.9
	Cd	0.001
	Cr	0.001
	Ni	0.03

Table 2. pH, EC, toxic elements and biological characteristics of LGW, Influent, and Effluent of Bani-Malik WWTP, along with standards of **MWE (2005) and FAO (1985).**

Parameter	Bani-Malik WWTP		LGW	MWE	FAO
	Influent	Effluent			
pH	7.29	7.45	7.89	6.0-8.4	6-9
EC (dS/m)	973.25	941.15	3510	3900	1920
Pb (mg/l)	0.022	0.019	0.004	0.1	0.5
Cd (mg/l)	0.0096	0.0091	0.0001	0.01	0.01
Cr (mg/l)	0.015	0.014	0.029	0.1	0.1
Ni (mg/l)	0.036	0.032	0.006	0.2	0.2
TDS (mg/l)	782.1	764.55	1612	2500	2000
SS (mg/l)	704.16	130.55	0	10	-
COD (mg/l)	532.51	170.4	0	150	-
BOD (mg/l)	324.85	48.62	0	10	-
Total coliform bacteria MPN/100ml	1212778	96294	0	1000	1000

Before installing the irrigation systems, the field was ploughed and leveled. In the subsurface drip irrigation systems, dripper lines were installed at 10 cm deep with 40 cm distance between two adjacent dripper lines. The distance between drippers was 45 cm with a discharge of 0.9 G/h *(RAIN BIRD LD- 06-12-1000 Landscape drip 0.9 G/h @18").* The downstream end of each dripper line was connected to a manifold for convenient flushing. Inlet pressure on each tape was approximately 1.5 bars. The system uses 125 micron disk filter to prevent blockage. The layout of the surface drip irrigation was exactly the same as in subsurface drip except for the positions of dripper lines, which were installed on the soil surface.

2.2. Cultural practices and Irrigation water requirements

The soil of the experimental site was prepared by ploughing and harrowing. Plots were classified according to the experimental design. Pre-recommended dose of phosphorus and potassium fertilization were added to the soil. The phosphorus fertilizer was added at a rate of 200 kg P_2O_5/ha as triple super-phosphate (46% P_2O_5) during the harrowing of the soil and before planting. Potassium fertilizer was added at a rate of 200 kg K_2O as potassium sulfate (50% K_2O) during the soil harrowing before planting. After the soil was prepared, irrigation systems were installed. After cultivation, hand weeding control was used to remove weeds during the growing seasons. In addition, the recommended doses of NPK fertilizers were fertigated in three equal doses with 10 day interval for each.

The required irrigation water was calculated based on crop water requirement (Evapotranspiration) and total available soil moisture. Evapotranspiration was calculated from reference evapotranspiration and crop coefficient based on the following equation:

$ET_c = K_c \times ET_o$

Where:

ET_c = crop evapotranspiration (mm/day)

ET_o= reference evapotranspiration (mm/day)

K_c= crop coefficient

Reference evapotranspiration was calculated from Penman-Monteith equation as described by **Allen et al. (1998).** Crop coefficients used in the calculation were taken from the values for vegetable crops listed in **Allen et al. (1998).** On the other hand, IWUE was obtained by dividing the total yield (kg/ha) by the seasonal irrigation water requirements (mm) including rain **(Howell, 1994).**

2.3. Data collection and analysis

Before harvesting, 10 randomly guarded plants/plots were chosen to measure the following traits for each plant/plot:

- Root length (cm)
- Fresh root weight/plant (g)
- Root yield/ha: fresh weight of the roots in 2x3 m/plot was determined and converted into yield

Plant samples were collected in sterile plastic bags and transferred directly to a microbiology Lab. A sample of 1 g of each plant part (root and leaf) was suspended in 10 ml sterile distilled water in 250 ml Erlenmeyer flask and mixed strongly for about 5 min. Serial dilutions were prepared from 10^{-1} to 10^{-5} and 0.1 ml from the stabile dilution was taken and spread on agar plates containing either nutrient agar or McConkey agar media to count total bacteria and Escherichia coli belonging to the coliform . Coliform bacteria are gram-negative bacilli that are found in the intestinal tract of humans and animals. It can ferment lactose in 24-48 h at 35°C. For this purpose a selective agar medium Mc Conkey was used. The probable presence of E. coli is indicated by the growth of red-pink non-mucoid colonies that is confirmed by biochemical tests, such as indole production **(Helrich, 1990).**

The toxic metals (Ni, Cd, Cr, Pb) were determined after digesting the plant and soil samples using the perchloric-nitric procedure of **Shelton and Harper (1941).** The concentration of these elements was measured using Inductively Coupled Plasma-Optical Emission Spectrometers (ICP-OES) Varian 720/730-ES series.

The collected data were statistically analyzed through various procedures and mean separation under the criteria of the Least Significant Difference (LSD) test. Analysis were carried out based on the experimental design and subject to the assumptions of the statistical analysis according to **Steel and Torrie (2000) as in El-Nakhlawy (2010).**

3. Results

3.1. Agronomic traits and Irrigation Water Use Efficiency (IWUE)

Results presented in Table 3 show that root length under surface drip was higher than that of subsurface drip irrigation during both growing seasons.

Table 3. Means of the studied agronomic traits and IWUE as affected by irrigation systems and wastewater treatments during 2011 and 2012 seasons.

Treat.	Agronomic traits						IWUE (kg/mm/ha)	
	Root length (cm)		Root weight/Plant		Root yield t/ha			
	2011	2012	2011	2012	2011	2012	2011	2012
Irrigation systems								
Surface	33.23^{a*}	24.08 ^{a}	256.00^{b}	520.25^{a}	24.683^{a}	46.829^{a}	94.2^{a}	115.1^{a}
Sub-surface	22.34 ^{b}	23.91 ^{a}	275.88^{a}	461.45^{b}	24.818^{a}	41.408^{b}	94.9^{a}	101.8^{b}
Wastewater treatments								
LGW	21.25^{c}	24.25^{abc}	268.87^{bc}	582.63^{a}	24.200^{bc}	52.475^{a}	92.5^{bc}	128.9^{a}
20T	21.30^{c}	21.75^{d}	158.25^{d}	338.50^{c}	18.953^{d}	30.450^{c}	66.8^{d}	74.8^{c}
40T	19.08^{c}	22.50^{cd}	232.12^{c}	450.88^{b}	20.913^{cd}	40.225^{a}	88.6^{c}	98.8^{b}
60T	27.25^{a}	25.50^{ab}	354.87^{a}	599.38 ^{a}	31.925^{a}	53.925^{a}	122.1^{a}	132.5^{a}
80T	21.60^{c}	23.75^{bcd}	256.25^{bc}	375.63^{c}	23.021^{cd}	33.800^{bc}	88.1^{c}	83.0^{bc}
100T	24.00^{b}	26.12^{a}	317.625^{ab}	598.13^{a}	28.575^{ab}	53.838^{a}	109.2^{ab}	132.3^{a}

*, Means followed by the same letter(s) are not significantly different according to LSD test at $p \le 0.05$.

In contrast, root weight/plant under subsurface drip was higher than that of surface drip irrigation in the first season, while the results of the second season showed a reverse order. Results also showed no significance difference in the root yield t/ha in the first season (values are nearly similar), while in the second season, surface drip showed higher yield than that of subsurface drip irrigation. IWUE was almost similar during the 2011 season. However, IWUE in 2012 was significantly higher under surface drip than that of subsurface drip irrigation.

The results of wastewater treatments clearly indicated that root length, root weight/plant per hectare, and IWUE were significantly higher in the 2012 season than that of 2011. Significant variations among treatments were found in the studied agronomic traits and IWUE. The highest root yield/ha, and IWUE were obtained from 60T and

100T treatments followed by LGW, 40T, 80T treatments, respectively. Conversely, the least production and IWUE were obtained under 20T (Table 3). Furthermore, the interaction effects between the two irrigation systems and wastewater treatments were not significant.

Table 4 Mean Numbers of fecal coliform on root and leaf under the effects of irrigation systems and wastewater treatments during 2011 and 2012 seasons.

Treatments	Root/gm		Leaf/gm	
	2011	2012	2011	2012
Irrigation system				
Surface	28.14^{a*}	26.18^{a}	2.50^{a}	5.78^{a}
Subsurface	15.6^{b}	18.98^{b}	2.38^{a}	5.62^{b}
Wastewater treatments				
LGW	1^{d}	1^{d}	1^{b}	1^{e}
20T	21^{c}	22.86^{c}	3^{b}	3.2^{d}
40T	22^{c}	23.8^{c}	4.5^{b}	4^{c}
60T	26^{ab}	26.6^{b}	5.5^{b}	5.5^{b}
80T	29^{ab}	27.53^{b}	5.5^{b}	5.86^{b}
100T	32^{a}	33.73^{a}	14^{a}	14.66^{a}

*, Means followed by the same letter(s) are not significantly different according to LSD test at $p \leq 0.05$

3.2. Toxic metals concentration in plant parts and soil

Results in Table 5 show no impact of irrigation systems on the mean values of toxic metals concentration, neither in the roots nor in the leaves of the plant during both growing seasons. However, a gradual and significant increase in the concentrations of toxic metals is depicted in both growing seasons as a result of the increase in wastewater percentage in the irrigation water. Hence, the least concentrations in both growing seasons were found in LGW treatment followed by 20T, 40T, 60T, 80T and 100T treatments, respectively.

The soil toxic metals results in the two growing seasons were found similar in trend to those found in plant parts (Table 6). There were no impact of irrigation systems on the concentrations of toxic metals..As in plant parts case, metal concentrations increased by the increase of wastewater percentage in the irrigation water. The least concentration values were found in the soils irrigated with LGW followed by 20T, 40T, 60T, 80T and 100T respectively.

3.3. Fecal coliform bacteria

The mean number of fecal coliform bacteria in root and leaves were significantly lower under the subsurface irrigation system than that of surface irrigation (Table 4). It was also lower in plant leaves than in plant roots. Moreover, there was a gradual increase in the number of fecal coliform associated with the increase in the wastewater percentage in the irrigation water. The least significant number of fecal coliform was found under LGW treatment followed by 20T, 40T, 60T, 80T and 100T treatments, respectively.

Table 5. Means of root and leaf toxic metal (mg/kg) concentration as affected by irrigation systems and wastewater treatment during 2011 and 2012 seasons.

Part of the plant	Treat.	Cd		Cr		Ni		Pb	
		2011	2012	2011	2012	2011	2012	2011	2012
	Irrigation system								
	Surface	0.012^{a*}	0.027^{a}	0.423^{a}	0.39^{a}	0.13^{a}	0.128^{a}	0.14^{a}	0.123^{a}
	Subsurface	0.011^{a}	0.29^{a}	0.475^{a}	0.40^{a}	0.12^{a}	0.126^{a}	0.11^{a}	0.126^{a}
	Wastewater treatments								
Roots	LGW	0.001^{f}	0.006^{d}	0.311^{c*}	0.25^{f}	0.02^{e}	0.04^{c}	0.032^{f}	0.03^{d}
	20T	0.004^{e}	0.013^{cd}	0.354^{b}	0.33^{e}	0.03^{e}	0.06^{bc}	0.061^{e}	0.04^{d}
	40T	0.007^{d}	0.018^{c}	0.518^{a}	0.38^{d}	0.06^{e}	0.09^{bc}	0.080^{d}	0.08^{cd}
	60T	0.01c	0.028^{b}	0.538^{a}	0.41^{c}	0.08^{d}	0.11^{b}	0.120^{c}	0.11^{c}
	80T	0.016^{b}	0.049^{a}	0.535^{a}	0.47^{b}	0.13^{c}	0.19^{a}	0.180^{b}	0.20^{b}
	100T	0.031^{a}	0.053^{a}	0.571^{a}	0.51^{c}	0.17^{b}	0.25^{a}	0.270^{a}	0.27^{a}
	Irrigation system								
	Surface	0.026^{a*}	0.013^{a}	0.12^{a}	0.26^{a}	0.019^{a}	0.02^{a}	0.14^{a}	0.18^{a}
	Subsurface	0.030^{a}	0.011^{a}	0.14^{a}	0.27^{a}	0.018^{a}	0.023^{a}	0.13^{a}	0.16^{a}
	Wastewater treatments								
Leaves	LGW	0.005^{f}	0.001^{e}	0.050^{d*}	0.058^{e}	0.002^{e}	0.002^{d}	0.04^{f}	0.04^{f}
	20T	0.011^{e}	0.004^{de}	0.07^{d}	0.102^{d}	0.007^{d}	0.009^{cd}	0.067^{e}	0.08e
	40T	0.018^{d}	0.007^{cd}	0.14^{c}	0.270^{c}	0.008^{d}	0.010^{c}	0.090^{d}	0.12^{d}
	60T	0.024^{c}	0.009^{c}	0.16^{c}	0.330^{b}	0.016^{c}	0.027^{b}	0.120^{c}	0.17^{c}
	80T	0.038^{b}	0.021^{b}	0.29^{b}	0.413^{a}	0.027^{b}	0.031^{b}	0.180^{b}	0.24^{b}
	100T	0.050^{a}	0.032^{a}	0.46^{a}	0.416^{a}	0.051^{a}	0.048^{a}	0.390^{a}	0.37^{a}

*, Means followed by the same letter(s) are not significantly different according to LSD test at $p \leq 0.05$

Table 6. Means of soil toxic metal contents (mg/kg) as affected by the irrigation systems and wastewater treatments at the end of 2011 and 2012 seasons.

Treat.	Cd		Cr		Ni		Pb	
	2011	2012	2011	2012	2011	2012	2011	2012
Irrigation system								
Surface	0.071[a*]	0.041[a]	0.142 [a]	0.14[a]	0.090[a]	0.074[a]	0.38[a]	0.40[a]
Subsurface	0.069[a]	0.04[a]	0.15 [a]	0.13[a]	0.08[a]	0.074[a]	0.26[a]	0.32[a]
Wastewater treatments								
LGW	0.009[b]	0.001[e]	0.068[c*]	0.081[d]	0.04[c]	0.05[d]	0.11[b]	0.12[d]
20T	0.64[ab]	0.008[ed]	0.12[bc]	0.085[d]	0.08[b]	0.051[d]	0.22[b]	0.22[c]
40T	0.068[a]	0.018[d]	0.13[abc]	0.105[cd]	0.08[b]	0.066[c]	0.27[b]	0.31[c]
60T	0.077[a]	0.003[c]	0.16[ab]	0.129[c]	0.09[ab]	0.073[c]	0.31[b]	0.41[b]
80T	0.086[a]	0.065[b]	0.18[ab]	0.172[b]	0.10[ab]	0.085[b]	0.39[ab]	0.51[a]
100T	0.115[a]	0.116[a]	0.21[a]	0.259[a]	0.12[a]	0.119[a]	0.63[a]	0.54[a]

*, Means followed by the same letter(s) are not significantly different according to LSD test at $p \leq 0.05$

Table 7. Comparison of obtained toxic metals concentration in plant parts and soil to WHO /FAO standard (2007) and European Union Standards EU, (2002).

Elements	WHO /FAO standard (2007)					EU, Standards (2002)		
	Plant				Cytotoxi Range *(mg/kg)	Soil		Cytotoxi Range *(mg/kg)
	2011		2012			2011	2012	
	Root	Leaf	Root	Leaf				
Cd	0.005-0.05	0.001-0.031	0.006-0.53	0.001-0.032	0.2	0.0009-0.115	0.001-0.116	3
Ni	0.03-0.28	0.002-0.051	0.04-0.25	0.002-0.048	1.5	0.04-0.125	0.05-0.119	75
Pb	0.032-0.27	0.04-0.39	0.03-0.27	0.04-0.37	5	0.112-0.63	0.12-0.54	300
Cr	0.211-0.571	0.054-0.46	0.25-0.51	0.058-0.418	5	0.068-0.216	0.081-0.259	150

3.4. Toxic metal concentrations versus international standards

Numerical comparisons between the obtained toxic metal results and the cytotoxic concentrations according to **WHO/FAO standard (2007)** for plants and the cytotoxic concentration of the soil toxic element according to European Union standards **(EU, 2002)** are presented in Table 7. Results showed that the ranges of the toxic metals (Cd, Ni, Pb, and Cr) in both plants and soils were less than those of cytotoxic concentrations reported by WHO/FAO and EU standards. Accordingly, there is no serious consequence to using the effluent of the WWTP under study to grow white radish.

4. Discussion

Two irrigation water treatments 60T and 100T produced the highest root yield/ha of white radish among the six wastewater treatments. This high production could be attributed to the increase in the absorption of macro and micro nutrients presented in the applied treatments. The presence of these nutrients was reflected by the increase in leaf area, yield components, and the total yield/ha. It is well known that, plant production is affected by four main environmental factors; these are light, temperature, water and nutrients. Under the current study the effects of light, temperature and water were the same for all treatments because all treatments were grown in the same field and received the same amount of irrigation water. Accordingly, the only factor that plays a significant role in the increase or decrease of the radish production is the nutrient elements. As wastewater percentage in the irrigation water increases, nutrient elements increase accordingly. Hence, the gradual increase in radish yield is attributed to the equivalent increase in the nutrients. Regardless to the experimental settings, irrigation systems, and water qualities, several researchers attributed the increase in crop production to the increase in nutrients availability **(Mandi and Abissy, 2000, Kouraa et al., 2002; Al-Lahham et al., 2003; Al-Abdulqader and Al-Jaloud, 2003; Munir and Mohammed, 2004; Lopez et al., 2006; Zavadil, 2009).**

The enhancement of growth abd yield in the second season compared to the first season could be due to the planting dates where the cultivation of the first season was in February while in the second season was in October. The difference in planting dates indicated two different environmental conditions, especially in arid regions. Consequently, the interaction between environmental factors was not the same in the two seasons. This in turn caused the plant to response differently. These findings are in line with those found by **Mandi and Abissy (2000), Kouraa et al. (2002), and Lopez et al. (2006).**

The increase of IWUE (total yield kg/ha divided by total water supply mm/ha) in season 2012 compared to season 2011 might be due to the high yield obtained during 2012 with a lower water supply than that of season 2011. The decrease in water supply during 2012 was due to the climate conditions of low air temperature and high relative humidity when the cultivation period spanned from October to December. Thus, the high yield associated with low water demand led to an increase in the values of IWUE. Similar results were obtained by **Ismail (2012).**

Results also revealed that increasing wastewater amount in the irrigation water increased total number of fecal coliform bacteria. Basically, the presence of any number of fecal coliform on the plant parts is an indication of microbial pollution. The high density of bacteria in the effluent of Bani-Malik WWTP definitely causes adverse health problems when consumed by humans and increases the risk of several diseases. These results strongly suggest the necessity to treat wastewater effluents to an extent that guarantees no or very few residual bacterial contaminants to be detected. Several studies have confirmed that secondary treated sewage effluent increases total coliform count **(Arafa et al. (2001) and Abdel-Magid (1996).** Researchers recommend that wastewater is acceptable for only restricted reuse in agriculture. These results are also in line with **Zhang et al. (2008)** who stated that, increasing the amount of wastewater irrigation, slightly increased microbial functional diversity. In spite of the presence of fecal coliform on white radish root, it can still be safely consumed. Hulling the roots before eating is necessary because hulling removes almost all the microbial pollution.

Increasing the amount of wastewater in the irrigation water accumulates toxic metals in plant parts and the soil of the crop. It might also increase the concentration of available nutrients on soil particles and soil solution. Similar results were reported by **Hundal and Arora (1993),** who confirmed that root crops such as radish, potato, carrot, and turnip generally accumulate less pollutant elements than leafy vegetables. A study conducted by **Brar et al. (2000)** also confirmed that irrigation with wastewater increased the concentration of Cr and Ni in soils, potato leaves, and potato tubers, but the increase in plants was less than that of soils. Lettuce and radish were found to be more likely than other vegetables to accumulate heavy metals in humans through the edible portion **(Intawongse & Dean, 2006)**. Plant Pb and Cd increase as wastewater irrigation application period increases **(Rusan et al., 2007).** The results of this research clearly indicate that the concentration of toxic metals in plant parts and soil is still far below the cytotoxic standards declared by **WHO-FAO (2007).** However, irrigation for long times with wastewater might elevate the concentration of these metals in the soil to a maximum permissible limit. It might take very long time to exceed the standard limits. In such cases, soil cleanup management like scheduled bioremediation may be recommended.

This study demonstrated that diluted wastewater can be used to grow white radish safely. As most root crops like white radish, the majority of microbial pollution is found on the outer part of the root, therefore, precautions that eliminates pollution like hulling the roots before eating is highly recommended.

5. Conclusions

This study confirmed that the agronomic traits, yield, IWUE, toxic metals, and fecal coliform bacteria of white radish were affected by the irrigation with wastewater qualities. The highest root yield/ha and IWUE were obtained from the treatments of 60T (60% wastewater) and 100T (100% wastewater. Due to the early cultivation in the second growing season, the total yield/ha and IWUE were higher than that of the first growing season.

The study also indicated that fecal coliform bacteria and toxic metals increase systematically in plant parts and soil as the amount of wastewater increase in the irrigation water. Noting that, the toxic metals concentrations were far below the cytotoxic standard published by WHO-FAO (2007) and EU (2002). The best treatments that produced the highest yield and IWUE with minimal microbial contamination were 60T and 100T; suggesting a safer use, better performance and considerable LGW conservation. In conclusion, the study confirms the safe use of diluted wastewater in growing white radish while precautions that eliminate microbial pollution before eating is highly recommended.

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