TREATED WASTEWATER USE AND ITS EFFECT ON WATER CONSERVATION, VEGETATIVE YEILD,YIELD COMPONENTS AND WATER USE EFFICIENCY OF SOME VEGETABLE CROPS GROWN UNDER TWO DIFFERENT IRRIGATION SYSTEMS IN WESTERN REGION, SAUDI ARABIA

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Abstract:

Irrigation with wastewater is a widespread observable fact in developing countries, especially those exhibiting arid climate conditions. Utilization of large volumes of domestic wastewater effluent is part of an overall integrated water resources management. The objective of this study was to investigate the effect of irrigation by six different treated domestic wastewater qualities on the yield of Cabbage and Lettuce crops under surface and Sub-surface drip irrigation systems. Field experiments were carried out during 2011 and 2012 seasons at the Agriculture Research station of King Abdulaziz University located at Hada Alsham area north east of Jeddah city. The six water qualities were prepared by diluting treated wastewater with local groundwater of the region. The dilution percentages were 0%, 20%, 40%, 60%, 80%, and 100% treated wastewater. Crop water requirement were calculated based of Penman Monteith equation for dry land condition and supplied daily to the crops. The obtained results showed significant impact of wastewater quality and irrigation system and their interactions on vegetative yield and yield components of both crops. Irrigation with 60% and 80% wastewater under sub-surface irrigation system produced the highest yield and yield components in both seasons. Irrigation Water Use Efficiency (IWUE) of cabbage crop increased under the use of subsurface drip irrigation while IWUE of lettuce crop increased under surface drip irrigation system. Among dilution percentages, the 60% gave the highest IWUE in both crops. In conclusion, this study implies an advantage of using treated wastewater in growing vegetable crops. This in turn saves considerable quantities of local groundwater resource.

Key Words: Wastewater, Irrigation system, Vegetabel crops, Yield, WUE, Water conservation

Introduction

Shortage of fresh water in arid and semi-arid regions like in Saudi Arabia increased the demand for using wastewater in agriculture sector. Using treated wastewater in agriculture is gaining tremendous popularity because of the wide range of benefits that accompany it. These benefits include conservation of fresh water, high level of organic matter and recycling of nutrients, thereby reducing the need to invest in chemical fertilizers (Al-Sha'lan, 2001). In Saudi Arabia, there are more that 30 desalination water treatment plants producing around 3 million m^3/day. Part of it is reused for agricultural purposes as an alternative resource for irrigation water. In an economical study of the use of recycled sewage water in irrigation of field crops, Al-Abdulqader and Al-Jaloud (2003) stated that it saved up to 45% in fertilizers cost for wheat crop and 94% for alfalfa crop compared to irrigation with well water due to the fact that sewage water contains the essential elements needed by such crops. They also indicated that the usage of treated sewage water in irrigating of wheat and alfalfa crops increased their yield by 11 and 23%, respectively, and consequently increasing the profit by 14 and 28%, respectively as compared to irrigation with well water.

In Dakar, Senegal, more than 60% of the vegetables especially lettuce and onion are grown in urban areas using a mixture of groundwater and untreated wastewater. About 20 million hectares in developing countries are irrigated with raw sewage or partially treated wastewater (Dreschel et al., 2002). Using wastewater in crop production sometimes decrease the quantity and quality of the yield however, it is possible to achieve high yields of crops without deterioration of their quality by using treated wastewater for the irrigation of crops under controlled conditions. This is evident was from large number of the previous researches as in (Najafi et al., 2003, Jimenez, 2005, Munir and Ayadi 2005, Esmailiyan et al., 2008 and Zavadil, 2009).

In spite of the benefits of using wastewater in crop production, the production is faced by some risks from heavy metal accumulation and microbial pollution. The main risk associated with wastewater irrigation is infection with intestinal helminthes (Mara and CainCross 1989). Depending on the source of the wastewater it might contain chemical pollutants and heavy metals that can accumulate in the soil and crops thereby posing a threat to human health. These risks can be greatly reduced by treating the wastewater before using it or by applying some precautions while using it. Such precaution include: partially treated, diluted with fresh water and using subsurface drip irrigation. The contamination of crops irrigated with municipal wastewater was not detected if the wastewater had been treated in stabilization ponds or disinfected, and if subsurface drip irrigation had been used (Vaz da Costa et al. 1996; Najafi et al. 2003; Panoras et al. 2003; Al-Lahham et al. 2003; Aiello et al. 2007). Excessive contents of heavy metals in crops irrigated with wastewater have not been reported (Zavadil 2009). Sometimes increasing the level of microbiological contamination than that reported by the WHO guidelines can be used for irrigation (Blumenthal et al., 2000 WHO, 2006). Many literatures indicate that the use of treated wastewater is partially safe for irrigation of some crops. The objective of this study was to investigate the effect of irrigation by six different qualities of treated domestic wastewater on the yield of Cabbage and Lettuce crops under surface and Sub-surface drip irrigation systems. This study and its results is part of a comprehensive project aims to investigate water resources conservation and the impact of irrigation by treated wastewater on the pollution and yield of some vegetable crops as well as soil contamination.

Materials and Methods

Experimental design

Cabbage and Lettuce cultivation experiments were carried out at the Agricultural Research Station of King Abdulaziz University (KAU), located at Hada AlSham village; 110 km north east of Jeddah city, Saudi Arabia. The soil at the experimental site is classified as sandy loam. The two vegetable crops were cultivated in strip plot design (Split block) with 4 replications; each of 2x3 m in size. The main plot treatments consist of two irrigation systems, surface and subsurface, while the sub plot treatments designed and arranged in strips containing six wastewater qualities.

Irrigation water source

Bani Malik wastewater treatment plant which is located in Jeddah city was the main source of irrigation water. Water was conveyed to the field site by trucks and stored into two large size reservoirs, each for an irrigation system. Reservoirs were also connected to six different storage tanks corresponding to six different wastewater qualities. The dilution process occurs within the storage tanks based on the desirable ratio of wastewater to local groundwater. The six wastewater qualities are: 0%, 20%, 40%, 60%, 80%, and 100%. The percentages indicate the wastewater portion. For example, 20% means one fifth as volume of wastewater mixed with four-fifths of local groundwater. Accordingly, the 0% and 100% corresponds to local groundwater and undiluted wastewater respectively.

Irrigation systems

Each water quality treatment of its corresponding irrigation system consists of storage tank with a capacity of 5000 L, disk filter, pump, controller, drip lines and solenoid to control flow time and irrigation interval. In sub-surface drip irrigation systems the field was leveled and the dripper lines were installed at 10 cm deep on 40 cm 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 about 1.5 bars. The system uses 125 micron disk filter to prevent blockage. The lay-out of the surface drip irrigation was exactly the same as in subsurface drip except for the positions of dripper lines, where they installed on soil surface.

Irrigation water requirements and supply

The required irrigation water was calculated based on crop water requirement (Evapotranspiration) and total available soil moisture. Evapotranspiration for each plant was calculated from reference evapotranspiration and crop coefficient as follows:

$$ET_c = K_c \times ET_o$$

Where:

Et_c : crop evapotranspiration (mm/day).

ET_o: Reference evapotranspiration (mm/day).

K_c: Crop Coefficient.

Reference evapotranspiration were calculated using Penman-Monteith equation as described by Allen et al., (1998). Also, crop coefficient values listed by Allen et al., (1998) for vegetable crops were used.

Data collection

Before harvesting, 10 random guarded plants per plot were labeled and three different traits were measured for each label. In Lettuce crop **(***Paris Island CV.)*, Plant height (cm), fresh foliage weight (g)/plant, and fresh foliage yield (t)/ha, while in Cabbage crop *(Brunswick CV.)*, head diameter (cm), fresh head weight (g) /plant and fresh head yield (t)/ha were collected and measured for two seasons 2011-2012.

Statistical Analysis

The collected data of each crop in each experiment was statistically analyzed using the analysis of variance procedures and mean separation under the criteria of Least

Significant Difference (LSD) test. The analysis was carried out based to the used experimental design, and after applying the assumptions of the statistical analysis according to El-Nakhlawy (2010).

Results and Discussion

Cabbage crop

Means of the studied traits of cabbage crop with their statistically comparisons using L.S.D. are presented in Table 1. Results indicated that sub-surface irrigation system significantly dominated over the surface irrigation in all studied traits in the first season (2011) while no significant differences were observed in the second season (2012). However, head yield/ha were the highest under the sub-surface irrigation in both seasons with values of 18.167 and 17.667 t/ha in 2011 and 2012 seasons, respectively. As for wastewater treatments effects, the obtained measurements revealed that the 0.0 % wastewater irrigation which is the local groundwater (LGW) had the highest mean values in all agronomic traits in the first season while no significant differences were detected in the second season. Apparently, yield and yield components are maximums when LGW is used for irrigation. This result is very clear in the first season, however, there are no distinct differences found among wastewater qualities in the second season.

Table 1. Means of the studied agronomic traits and irrigation water use efficiency of Cabbage crop under the effects of irrigation systems and wastewater qualities during 2011 and 2012 seasons.

Treatment	Agronomic traits								IWUE (kg/mm/ha)	
	Plant Height (cm)		Head diameter (cm)		Head weight/Plant (g)		Head yield/ha (t)			
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Irrigation system										
Surface	11.29 b*	15.16	9.43 b	11.28	154.15 b	229.44	15.679 b	16.178	25.7 b	76.8 a
Sub-surface	13.88 a	14.84	15.0 a	11.23	180.04 a	236.08	18.167 a	17.667	30.1 a	76.9 a
Waste water percentage in Irrigation water (%)										
0.0	16.63 a	15.12	20.15 a	11.18	225.61 a	232.22	20.650 a	26.286	37.7 a	81.7 ab
20	11.65 c	14.54	11.3 b	11.94	176.11 b	232.3	18.075 b	25.481	25.1 cd	69.1 e
40	12.66 b	14.66	10.85 b	11.08	170.06 b	230.92	17.188 b	27.954	26.9 bc	74.6 cd
60	13.43 b	14.89	11.06	11.1	173.29	231.94	15.825 c	26.661	28.9 b	84.1 a

			b	0	b					
80	10.70 d	15.06	9.98 b	11.50	136.62 c	233.94	15.137 cd	26.367	23.4 d	70.4 de
100	10.44 d	15.18	9.13 b	11.41	125.79 d	235.38	13.662 d	26.286	25.4 cd	77.6 bc

***, Means followed by the same letter(s) are not significantly different according to LSD test at p ≤ 05.**

Irrigation water use efficiency (IWUE) under the current study is defined as crop yield per unit of applied water. The last column of Table 1 shows the obtained values of IWUE for both seasons under surface and subsurface irrigation systems as well as wastewater qualities. The value of IWUE increased under sub-surface drip irrigation in the first growing season compared to surface irrigation. Conversely, no change was obtained in the second growing season. As of wastewater quality effect, LGW resulted in the highest IWUE value in the first season followed by 60%, and 40% wastewater qualities respectively. The least IWUE was obtained under the application of 80% wastewater quality. On the other hand, the second season results demonstrated slight change in the order of wastewater quality influence. The highest IWUE (84.1 kg/mm/ha) was obtained under the 60% wastewater quality while the lowest (69.1 kg/mm/ha) was under 20%.

Table 2 shows the interaction between irrigation system and wastewater quality of cabbage traits. Clear discrepancies were found in the results between the two seasons. Significant differences were depicted in the first season on plant height, head weight/plant, and head weight/ha, while no significant effects were noticed between trait means in the second season. An interesting negative regression between head yield/ha and applied water qualities was observed in both surface and sub-surface irrigation systems, especially in the first season. The highest head yield (22.525 t/ha) was produced under LGW and the lowest (11.13 t/ha) was under the application of 100% wastewater. On the other hand, no significant differences were shown in the values of yield under sub-surface irrigation system in all applied water qualities in the 2nd season.

Means of head weight/plant results were almost similar in trend to that of head yield/ha. The negative regression between wastewater and head weight/plant also applies here not only in the first season as in the case of head yield/ha but also in the 2nd season. Though, the second season showed no significant differences. Similarly, the two other yield components, head diameter and plant height followed the same trend but less affected. On the other hand, the highest IWUE was obtained under LGW in both irrigation systems in the first season. In the second season, however, the highest IWUE were obtained with the use of 60% (90.62 kg/mm/ha) and LGW (85.50 kg/mm/ha) water qualities under sub-surface and surface irrigation system respectively.

Lettuce crop

Comparison of agronomic traits of lettuce crop under surface and sub-surface drip irrigation systems are shown in Table 3. Results confirmed that vegetative yield/ha and weight/plant were significantly higher in surface irrigation than that of sub-surface irrigation system. Vegetative yield/ha were 46.83 and 48.98 t/ha under the surface irrigation and 40.59 and 42.76 t/ha under the sub-surface irrigation in 2011 and 2012 seasons, respectively.

Table 2. Means of agronomic traits and irrigation water use efficiency of Cabbage crop under the effects of the interaction between irrigation systems and wastewater qualities during 2011 and 2012 seasons.

Irrigation System	**Waste water (%)**	**Agronomic traits**								**IWUE (kg/mm/ha)**	
		Plant Height (cm)		**Head diameter (cm)**		**Head weight/Plant (g)**		**Head yield/ha (t)**			
		2011	**2012**	**2011**	**2012**	**2011**	**2012**	**2011**	**2012**	**2011**	**2012**
Surface	**0.0**	15.58	15.57	11.00	11.13	222.53	232.57	22.525	26.761	37.55	85.50
	20	11.00	14.79	10.13	10.99	165.35	229.95	18.200	24.650	25.43	58.75
	40	11.58	14.57	9.86	11.03	156.90	225.13	15.200	28.912	26.51	71.87
	60	12.05	14.99	9.80	11.05	154.25	226.87	14.275	26.431	27.28	78.27
	80	9.33	15.32	11.21	11.83	107.83	230.52	12.750	25.756	18.05	80.35
	100	8.22	15.70	6.64	11.64	101.76	231.60	11.125	25.900	19.30	79.72
Sub-surface	**0.0**	17.43	14.67	11.03	11.24	224.70	231.87	18.775	25.811	37.88	77.85
	20	12.25	14.30	11.02	11.49	186.88	234.65	19.950	26.311	24.73	79.45

	40	13.57	14.76	10.14	11.14	183.23	236.71	19.175	26.996	27.35	77.40
	60	14.88	14.80	10.16	11.16	172.23	237.01	17.375	26.892	30.42	90.62
	80	12.18	14.08	10.19	11.17	165.40	237.36	17.525	26.979	28.75	60.50
	100	12.60	14.66	11.21	11.19	149.83	238.89	16.200	26.800	31.53	75.40
LSD(0.05)		**1.27**	**NS**	**1.64**	**NS**	**22.31**	**NS**	**5.169**	**NS**	**3.85**	**6.31**

The effect of wastewater quality application on yield/ha and weight/plant was almost the same in both seasons. Obtained values of these two yield components can be classified in two categories. The first category which is the irrigation with LGW, 60%, and 100% wastewater qualities produced higher yield/ha and weight/plant than the second category which is 20%, 40, and 80%. The lowest values of yield/ha and weight/plant were obtained under the cultivation of the crop under 20% wastewater treatment in both seasons.

Surface drip irrigation significantly increased IWUE during the first growing season compared to sub-surface drip irrigation. However, in the second season the case was reverse, where IWUE was higher under subsurface irrigation (Table 3). The high values of IWUE recorded during the first growing season were under the irrigation with 60%, 100% and LGW qualities, where they were almost similar; followed by 40% and 80%. The least IWUE was obtained under 20% treatment. It can be concluded that the trend of IWUE is similar to that of yield/ha and weight/plant. In the second growing season the highest IWUE was obtained by 100% and 60% with no significant differences between them; followed by LGW, 80%, and 40%. The least IWUE was obtained under the 20% wastewater quality.

Table 3. Means of the studied agronomic traits and irrigation water use efficiency of Lettuce crop under the effects of irrigation systems and wastewater qualities during 2011 and 2012 seasons.

Treatment	**Agronomic traits**						**IWUE (kg/mm/ha)**	
	Plant Height (cm)		**Vegetative Weight//Plant (g)**		**Vegetative yield/ha (t)**			
	2011	**2012**	**2011**	**2012**	**2011**	**2012**	**2011**	**2012**
Irrigation system								
Surface	24.13	27.13	520.25 a	564.33 a	46.83 a	48.98 a	202.3 a	188.0 a
Sub-surface	23.92	25.92	461.46 b	529.29 b	40.59 b	42.76 b	178. 9 b	196.5 a
Waste water percentage in Irrigation water (%)								
0.0	23.88 b	24.85 a	582.63 a	645.88 a	52.49 a	52.98 a	226.7 a	204.1 ab
20	20.38 c	22.21 b	338.50 c	351.75 e	31.70 b	30.4 d	131.5 c	128.6 c
40	24.25 b	24.76 a	450.88 b	506.50 d	40.23 b	48. 3 c	173.8 b	181.5 b
60	25.38 ab	26.46 a	599.38 a	592.13 bc	53.94 a	50.73 b	233.0 a	215.0 a
80	24.13 b	24.08 b	428.85 b	570.38 c	33.80 b	48.21 c	146.0 bc	204.3ab
100	23.88 b	26.32 a	598.13 a	614.25 ab	53.85 a	51.84 ab	232.6 a	219.7 a

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

Table 4 shows results of the interaction between irrigation systems and wastewater qualities. A significance interaction was obtained in the first season only. The 60% wastewater quality and LGW produced the highest vegetative yield/ha under surface irrigation system with values of 57.95 and 56.63 respectively. On the other hand the 80% and 100% wastewater quality responded identically with a value of 57.2 under sub-surface irrigation.

Highest weight values of vegetative weight/plant were 644.23, 628.25, 586.77, and 561.01 under the surface irrigation corresponding to 60%, 0.0%, 40%, and 100% wastewater respectively. The order of water quality however is different in the sub-surface irrigation system. The highest values of weight/plant were obtained with 100% and 80% wastewater quality corresponding to values of 635.25 and 554.50 respectively (Table 4).

Table 4. Means of agronomic traits and irrigation water use efficiency of Lettuce crop under the effects of the interaction between irrigation systems and wastewater qualities during 2011 and 2012 seasons.

Irrigation System	Waste water (%)	Agronomic traits						IWUE (kg/mm/ha)	
		Plant Height (cm)		Vegetative Weight/Plant (g)		Vegetative Yield (t/ha)			
		2011	2012	2011	2012	2011	2012	2011	2012
Surface	0.0	24.50	25.00	628.25	625.70	56.63	45.90	244.60	194.50
	20	21.24	24.50	398.11	346.00	38.30	29.63	154.65	125.57
	40	25.76	26.75	586.77	480.00	52.80	52.80	228.08	181.40
	60	25.48	25.50	644.23	583.25	57.95	48.42	250.32	205.20
	80	22.00	25.50	303.21	569.00	57.30	46.43	117.90	196.72
	100	25.75	26.00	561.01	571.75	50.50	52.99	218.17	224.55
Sub-surface	0.0	23.23	26.00	537.12	666.00	48.34	50.60	208.78	214.40
	20	19.49	24.75	279.00	357.50	25.10	31.07	108.43	131.67
	40	22.76	25.50	315.20	533.00	49.92	42.87	119.42	181.67
	60	25.23	25.00	448.11	601.00	40.30	53.02	215.65	224.70
	80	26.25	25.00	554.50	571.75	57.20	45.00	174.08	211.87
	100	26.51	26.50	635.25	625.70	57.20	50.70	246.97	214.82
LSD(0.05)		2.21	NS	103.25	NS	9.33	NS	40.16	NS

The highest IWUE during the first growing season obtained under 60% wastewater quality followed by LGW under surface drip irrigation. In subsurface drip irrigation, the highest IWUE obtained by 100% followed by 60% and LGW. In the second growing season however there was a slight change in the order of the high and low values, where the highest IWUE was found with 100% followed by 60% and LGW under surface irrigation system. Likewise, under subsurface drip irrigation system, the highest IWUE was obtained under 60% followed by 100% and LGW.

The descending yield of Cabbage crop with ascending concentration of wastewater especially in the first season could be attributed to adverse impact of wastewater on the crop due to the accumulation of micro and toxic elements in stem and leaves of the plant. Consequently, the metabolic processes and total yield of cabbage tend to decrease. This response depends on the interaction between crop genetic makeup and the wastewater concentration in irrigation water (G x E interaction) as reported by Ba-Sahi et al., (2007) and Khan et al., (2009). A study by Ahmed (2011) has also supported our results where he reported that the application of increasing doses of municipal wastewater reduces the overall yield of some vegetable crops.

On the other hand, the positive responses of using wastewater in irrigation of lettuce crop, especially under the sub-surface irrigation system, may be due to the increase in the absorption of macro and micro elements in the wastewater which was reflected in the increase of leaf area and yield components and finally the increase in yield/ha.

In general, the obtained results illustrated the significant interaction between the economic part of the crop and water quality, especially the (%) of wastewater in the irrigation water of the agricultural crops. The positive effects of irrigation with 40% and 60 % of wastewater might be due to the increase in the nutrients of the soil under wastewater irrigation. These nutrients may improved the physical and nutrient contents of the soil, hence significantly increased the total chlorophyll and carotene and established good growth and increased biomass and yield of the crop. This justification is supported by many independent studies (Singh and Agrawal , 2009, Khan et al., 2011 and Thapliyal et al., 2011). Moreover, Zavadil (2009) reported that the primary-treated wastewater increased the yield of all vegetables crops, the increase having been statistically significant in most cases.

As indicated by the results of IWUE especially in cabbage crop, sub-surface drip irrigation generally increase IWUE compared to surface drip irrigation. Since the amount of irrigation water supply was the same for both irrigation systems, hence increasing IWUE is an indicator for higher crop production. The increase in IWUE under sub-surface drip irrigation might be due to the minimal losses under subsurface drip compared to surface drip. In addition, no surface evaporation in sub-surface drip occurs, compared to drip irrigation (Phene et al. 1992, Ismail and Almarshadi, 2011). Soil moisture content under subsurface drip irrigation was more uniform as compared with surface drip. Soil water data of sub-surface irrigation suggest little or no potential for deep percolation losses. As a result, crop production is increased with the same amount of water supply, consequently IWUE is increased. Support to this point can be found in Hutmacher et al. (1992) and Senyigit et al., (2011) studies. The scope of losses due to deep percolation and surface evaporation is greatly reduced by sub-surface drip irrigation as found by Alam et al. (2002). Sometimes surface drip irrigation increase yield production compared to sub-surface irrigation as found in Lettuce. The results could be due to the root distribution behavior of lettuce where they highly presented in surface layer. The Increase of IWUE in the second season compared to the first season might be due to the change in planting date, metrological conditions, length of the growing period and photo period.

Conclusion

The response of the two growing seasons to yield and yield components was different. In the first season there was almost an inverse proportionality between the agronomic traits and the irrigated wastewater quality in Cabbage crop. As wastewater quality increase, yield and yield components decrease. This proportionality does not exist in the second season where no significant differences were found in the values of all agronomic traits. The response of Lettuce crop on the other hand is quite different from that of Cabbage. There was no clear relationship between the agronomic traits and the applied water qualities. However, the Local groundwater quality, 60% and 100% wastewater qualities produced the highest yields in both seasons. Thus, there was a similarity in the response of the two seasons. On the other hand, contrasting proportionality was found under the interaction between irrigation system and wastewater quality not only in the two growing seasons but also between the two crops.

There was found high discrepancies in the IWUE values between the two seasons and less discrepancy between the two irrigation systems. In addition, the IWUE response to Cabbage and Lettuce crops was unlike. The sub-surface irrigation system produced higher value of IWUE compared to surface irrigation in Cabbage crop. However, the case is reverse in Lettuce crop. There was also a significant increase in IWUE values in the second season of Cabbage crop. This increase reaches up to two to three times. IWUE is an indicator of not only of crop yield but also water savings. In this study, a considerable saving of water resources was attained. Among all investigated wastewater treatments, 60% found the best because it saved 60% of natural clean water resources. In another word, 60% of treated wastewater which could have been disposed unsafely in the environment has been utilized in the production of vegetable crops.

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