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Original Research

Effect of Different Irrigation Sources on Growth, Yield and Heavy Metals Accumulation in Tomato and Okra

Safina Naz*, Muhammad Akbar Anjum and Sakeena Tul Ain Haider
Department of Horticulture, Faculty of Agricultural Sciences and Technology, Bahauddin Zakariya University, Multan

ABSTRACT

Field experiments were conducted to investigate the effects of different irrigation sources (canal, tube-well and sewage) on growth, yield and heavy metal uptake of two summer vegetables i.e. tomato and okra. Growth attributes (plant height, number of leaves, relative leaf chlorophyll content and leaf area) and yield components (number of fruits / pods per plant and fruit size) of okra and tomato were significantly increased with sewage water application. Lesser growth and yield of the studied vegetables was recorded with tube-well water. Use of sewage water improved total yields and fresh and dry plant biomass production of both the vegetables. Significantly higher and lower lead (Pb), copper (Cu), cadmium (Cd), nickel (Ni), chromium (Cr) and iron (Fe) contents were recorded in edible parts of the sewage and tube-well water irrigated vegetables, respectively. Edible parts (tomato fruits and okra pods) of the sewage water irrigated vegetables exhibited heavy metals contents above the maximum permissible limits. Leaf and root samples of the sewage water irrigated tomato and okra also contained significantly greater metals contents as compared to those irrigated with canal and tube-well water. It is concluded that vegetables irrigated with sewage water produced greater yields but these were found contaminated with heavy metals.

Keywords: *Cadmium, canal water, chlorophyll content, chromium, copper, iron, lead, nickel, plant biomass, sewage water, tube-well water*

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INTRODUCTION

Freshwater is an inimitable natural source with fascinating qualities. Worldwide availability of clean water is deficient as its demand has increased three folds since 1950s mainly in countries of African, Middle Eastern and South Asian regions (Gleick, 2003). There are several contributing factors leading to water shortage in Pakistan including poor distribution systems of irrigation, salty ground water, rapid population growth and frequent drought conditions. This situation has led to the application of untreated city waste water for irrigating agricultural lands which has now become a common and prevalent practice in Pakistan especially in peri-urban areas (Khalil and Kakar, 2011) and in many other developing countries of the world (Sharma et al., 2007; Nagajyothi et al., 2009; Nath et al., 2009).

Waste water is a possible source of organic and inorganic elements needed for plant growth (Ramirez-Fuentes et al, 2002; Khan et al., 2013; Mosleh and Almagrabi, 2013). Farmers exploit waste water for irrigation in farming areas located in the vicinity of cities or around the industrial zones, considering this type of water as valuable and inexpensive source of nutrients and an appropriate alternative of fertilizers (Qadir et al., 2008; Murtaza et al., 2010). Waste water holds vital nutrients for plant growth such as N, P and K, and micronutrients including Fe, Mn, Zn and Cu in addition to a substantial quantity of organic matter that contributes to enhance crop productivity (Rai et al., 2011; Ullah et al., 2011; Gosh et al., 2012). The increased growth and yield of corn raised by application of sewage water was ascribed to the presence of macro and micronutrients in waste water (Harati, 2003). Similar results were reported by Segura et al. (2002) suggesting significant increase in the yield of tomato and melon irrigated with waste water grown in greenhouse. Chalkoo et al., (2013) noticed that application of waste water along with phosphorus fertilization significantly increased growth with improved physiological, biochemical and yield attributes of chilli.

Waste water irrigation is generally considered as a main cause of buildup of heavy metals in the soils (Mapanda et al., 2005; Sharma et al., 2007; Ullah et al., 2011; Mosleh and Almagrabi, 2013). Excessive accretion of heavy metals in farming soils irrigated with waste water, not only cause soil contamination, but also contribute to elevate the levels of heavy metal accumulation in plants and thus jeopardize the food value and safety of the crops (Muchuweti et al., 2006). According to WHO (1996), recommended safer levels of various heavy metals for intake of human are Pb (2 mg/kg), Ni (10 mg/kg), Cu (10 mg/kg), Fe (150 mg/kg), Cd (0.02 mg/kg) and Cr (1.3 mg/kg). Intake of heavy metals through contaminated vegetables can exert a substantial health threat to humans, predominantly in levels exceeding the body needs (Banerjee et al., 2011). These metals, being highly toxic and non-biodegradable, damage

* Corresponding author.
E-mail: safina_bzu@yahoo.com, safinanaz@bzu.edu.pk (S. Naz)

human health when ingested even at parts per billion (ppb) level. These are gradually released into the body and can cause several diseases (Singh et al., 2010). The harmful impacts of heavy metals include incurable, neurotoxic, mutagenic, carcinogenic and teratogenic consequences (Sharma et al., 2008; Patra et al., 2010). The elevated heavy metals contents have also been reported to negatively influence blood acidity, and cause retardation, kidney damage, different types of cancer and even death among humans. This situation might become shocking for vegetarians as their main component of the food include fresh vegetables.

Food safety is one of the most pressing challenges. Evidence is available to suggests that majority of Pakistani foods are drastically implicated with contaminants like heavy metals; hence pose a dreadful threat to the human health and well-being (Akhtar, 2015). There is an increasing demand for food safety measures, which has stimulated researchers to evaluate food stuffs contaminated with heavy metals, which may cause health risks upon their consumption (D'Mello, 2003). In view of these facts, this study was envisaged to evaluate the growth, yield and accumulation of heavy metals in two summer vegetables (tomato and okra) grown in peri-urban areas of Multan, Pakistan irrigated with different sources of water (tube-well, canal and sewage water).

MATERIALS AND METHODS

The research trials were conducted to evaluate the growth, yield and accumulation of heavy metal contents in two summer vegetables (tomato and okra) grown in peri-urban area of Multan, Pakistan. Field trials were conducted on the selected sites during summer season of two consecutive years (2011 and 2012). There were three treatments (different sources of irrigation) viz. canal, tube-well and sewage water. The experiments for each vegetable were conducted independently in randomized complete block design (RCBD) having factorial arrangements with three replications.

Cultivation of Vegetables

Tomato (*Lycopersicon esculentum* Mill.)

Six weeks old seedlings of tomato cv. Roma were obtained from local Market and transplanted on 10th February 2011 (1st year crop) and 10th February 2012 (2nd year crop). The seedlings were transplanted on both sides of 1 m wide beds with plant to plant spacing of 60 cm. The size of each experimental plot was 11.70 m^2. The plot was irrigated immediately after transplanting and succeeding irrigations were applied according to the crop requirements. Total three hoeing were carried out during entire period of cultivation to eradicate the weeds. The crop was fertilized with N:P:K (100:80:40 kg/ha) by using urea, diammonium phosphate (DAP) and sulphate of potash (SOP).

Okra (*Abelmoschus esculentus* (L.) Moench)

Seeds of okra cv. Sabz pari were sown on 5th March 2011 (1st year crop) and 5th March 2012 (2nd year crop). The seeds were sown on both sides of ridges prepared 60 cm apart, keeping plant to plant distance 20 cm. The size of individual experimental unit was 3.76 m^2. Okra was irrigated instantly after sowing and the rest of the irrigations were applied according to requirements of the crop. To control weeds, three hoeing were carried out during the entire crop growth period. The plants were fertilized with N:P: K @ 120:100:40 kg/ ha by applying urea, DAP and SOP.

Data Collection

Data on various growth parameters were collected at vegetative phase. Data on yield and its related parameters were taken at the times of harvestings. Samples of fruits, pods, leaves and roots of tomato and okra were collected after harvesting for analysis of heavy metals (Pb, Ni, Cu, Fe, Cd and Cr) in different parts of the selected vegetables. The analysis for heavy metals in samples collected during the course of experiments was performed in the Laboratories of Department of Horticulture and Department of Food Science and Technology, Bahauddin Zakariya University, Multan.

Determination of Heavy Metals

Pre-Treatment

The dust particles were removed from the collected vegetable samples by washing them with distilled water and then air-dried in shade for one hour. The vegetable samples were sliced into pieces and placed in an electric oven (Memmert-100, Germany) at 70 °C for 72 hours. Dried vegetable samples were ground with a pestle in a mortar to a fine powder and sieved through a muslin cloth. All the powdered samples were saved in polythene bags until used for analysis.

Chemicals

All the required chemicals (analytical grade) and standards of heavy metals (1000 mg L^{-1}); namely lead (Pb), copper (Cu), nickel (Ni), cadmium (Cd), iron (Fe) and chromium (Cr) were obtained from Merck. All the glassware used was washed with detergent and finally rinsed with distilled water.

Acid Digestion and Analysis

For heavy metals extraction, 0.5 g dried sample (three replicates for each vegetable) from each treatment were digested in 15 mL HNO_3 and 5 mL $HClO_4$ mixture (3:1) on a hot plate (Velp, Italy) at 80 ºC until a transparent solution was obtained. These transparent solutions were filtered through Whatman No. 42 filter paper and diluted in 25 mL deionized water (Farooq *et al.*, 2008). The concentrations of heavy metals (Pb, Ni, Cu, Cd, Fe and Cr) in the filtrate were determined by using an atomic absorption spectrophotometer (Thermo Scientific 3000 series, USA).

Statistical Analysis

The data recorded were subjected to analysis of variance (ANOVA). The experiments for each vegetable were conducted independently in randomized complete block design (RCBD) having factorial arrangements with three replications. Least Significant Difference (LSD) test was employed to evaluate

Table 1: Effect of different irrigation sources on growth of tomato and okra.

Source of irrigation	Tomato			Okra		
	Year 2011	Year 2012	Mean	Year 2011	Year 2012	Mean
Plant height (cm)						
Canal	82.37a	87.67a	85.02b	86.90a	81.67a	84.28b
Tube-well	85.22a	81.00a	83.12b	80.80a	83.83a	82.31b
Sewage	92.07a	92.06a	92.06a	94.40a	88.33a	91.36a
Mean	*86.56a*	*86.91a*		*87.37a*	*84.61a*	
Relative leaf chlorophyll content (SPAD values)						
Canal	45.37a	50.10a	49.55b	58.23a	55.00a	56.61ab
Tube-well	54.67a	49.00a	50.02b	54.36a	53.00a	53.68b
Sewage	66.33a	62.50a	64.42a	62.00a	58.00a	60.00a
Mean	*52.66a*	*56.67a*		*58.20a*	*55.33a*	
Leaf area (cm^2)						
Canal	19.52a	21.93a	22.66b	60.96a	62.00a	61.48b
Tube-well	20.52a	23.39a	20.02c	52.13a	51.33a	51.73c
Sewage	26.47a	24.17a	25.32a	69.63a	66.33a	67.98a
Mean	*21.87a*	*23.46a*		*60.91a*	*59.88a*	

Mean values sharing different letter(s) in a group are significantly different at $p \geq 0.05$.

Table 2: Effect of different irrigation sources on yield components of tomato and okra**.**

Source of irrigation	Tomato			Okra		
	Year 2011	Year 2012	Mean	Year 2011	Year 2012	Mean
Number of fruits/pods per plant						
Canal	24.33a	24.83a	24.58b	22.67a	20.67a	21.67b
Tube-well	23.56a	24.43a	24.00b	22.33a	20.17a	21.25b
Sewage	28.00a	28.13a	28.06a	27.17a	24.00a	25.58a
Mean	*25.30a*	*25.80a*		*24.06a*	*21.61a*	
Fruit/pod length (cm)						
Canal	5.60a	5.67a	5.63b	10.70a	12.00a	11.35b
Tube-well	5.20a	5.13a	5.17c	9.50a	8.67a	9.08c
Sewage	5.83a	5.87a	5.85a	12.05a	14.33a	13.19a
Mean	*5.54a*	*5.56a*		*10.75a*	*11.67a*	
Fruit/pod diameter (cm)						
Canal	6.75a	6.95a	6.85a	1.13a	1.13ab	1.13a
Tube-well	6.80a	7.10a	6.95a	1.12a	1.07b	1.12a
Sewage	6.87a	7.40a	7.13a	1.20a	1.21a	1.20a
Mean	*6.80a*	*7.15a*		*1.15a*		*1.15a*

Mean values sharing different letter(s) in a group are significantly different at $p \geq 0.05$.

significant differences among the treatment means at probability level of 5%. Statistical software Statistix 8.1 was used to analyze the data (Steel et al., 1997).

RESULTS

Plant Growth

The data procured during the two years of study on growth of tomato and okra is presented in Table 1. The growth of these crops in terms of plant height, relative leaf chlorophyll content and leaf area was significantly affected by the irrigation sources. Sewage water resulted in greater plant height and relative leaf chlorophyll content when compared with canal water or tube-well water (Table 1). There was no significant difference in plant height and relative leaf chlorophyll content under tube-well water and canal water irrigation. Sewage water also resulted in the maximum leaf area of tomato and okra, which was followed by canal water and it was reduced significantly in plots where tube-well water was applied. However, these three treatments differed significantly from each other (Table 1).

Yield Attributes and Final Yield

Irrigation sources significantly affected number of fruits per tomato plant, number of pods per okra plant, fruit length of tomato, and pod length and diameter of okra. Significantly greater number of tomato fruits and okra pods per plant was produced due to sewage water irrigation. Canal and tube-well water irrigation resulted in statistically similar number of tomato fruits and okra pods. Longer tomato fruits and okra pods were produced in sewage water irrigated plants, which was followed by canal water irrigated plants. However, these two irrigation sources were statistically different. Fruit and pod length were the shortest in the plants grown with tube-well water. Sewage water also resulted in the maximum pod diameter, followed by canal water, both the irrigation sources behaved statistically alike. The minimum diameter was recorded in the pods harvested from the tube-well water irrigated okra, followed by canal water irrigated ones. These two irrigation sources were also statistically similar (Table 2). Significantly greater fresh and dry weights per fruit and fruit yield per hectare of tomato were recorded from sewage water irrigated plants, followed by those irrigated with canal water, whereas the minimum fresh and dry fruit weights and yield were recorded in the plants irrigated with tube-well water. However, these three irrigation sources differed significantly from each other. Similarly, significantly greater fresh and dry weights per okra pod were observed in sewage water irrigated plants. Whereas, tube-well water resulted in lower fresh weights per pod, which were statistically at par with canal water. The maximum tomato fruit yield and okra pod yield per hectare were attained with sewage water irrigation, which were significantly greater than those of canal and tube-well water. Whereas, the minimum yields were recorded with tube-well water irrigation. These three irrigation treatments were statistically different from each other (Table 3). The interaction between irrigation sources and years also had significant effect on fresh and dry weights of tomato fruit. Significantly greater fresh and dry fruit weights were recorded with interactive effect of sewage water × 2012 and sewage water × 2011. These two treatment combinations were statistically at par. The minimum fresh and dry weights of tomato fruit were recorded with the combined effect of tube-well water × 2012, which was also statistically at par with the treatment combination tube-well water × 2011 (Table 3).

Biomass Production (on fresh and dry weight basis)

Various irrigation sources applied had significant influence on total fresh and dry plant biomasses of both tomato and okra. Significantly greater total fresh and dry plant biomass was observed in the sewage water irrigated plants compared with canal and tube-well water irrigated plants. Whereas, canal and tube-well water were statistically similar with lower total biomass (Table 4).

Heavy Metals Contents in Tomato Fruits and Okra Pods

Significantly higher Pb and Ni contents were recorded in both sewage water irrigated tomato and okra plants, preceded by those irrigated with canal and tube-well (Table 5). Canal and tube-well water were statistically similar with lower contents (Pb and Ni). Sewage water irrigated tomato plants also contained significantly greater Cd, Cu, Fe and Cr contents in their fruits. Whereas, significantly lower Cd, Cu, Fe and Cr content were recorded in tube-well water irrigated fruits. Greater Cd content was recorded in pods of the sewage water irrigated okra plants compared with those irrigated with canal or tube-well water. Whereas, the minimum and statistically similar Cd content was recorded in canal and tube-well water. Sewage water also resulted in significantly greater Cu, Fe and Cr contents in okra pods, followed by canal water. However, these two irrigation sources were significantly different from each other. Whereas, significantly lesser contents (Cu, Fe and Cr) were

Table 3: Effect of different irrigation sources on yield of tomato and okra.

Source of irrigation	Tomato			Okra		
	Year 2011	Year 2012	Mean	Year 2011	Year 2012	Mean
Fresh weight per fruit/pod (g)						
Canal	90.73b	90.43b	90.58b	9.05a	9.53a	9.29ab
Tube-well	88.46bc	87.93c	88.29c	8.52a	9.03a	8.77b
Sewage	93.77a	95.00a	94.4a	9.40a	10.17a	9.78a
Mean	*90.99a*	*91.12a*		*8.99a*	*9.58a*	
Dry weight per fruit/pod (g)						
Canal	9.65b	9.62b	9.63b	1.11a	1.17a	1.14b
Tube-well	9.34c	9.23c	9.28c	1.38a	1.45a	1.41b
Sewage	9.97a	10.10a	10.04a	1.69a	1.86a	1.77a
Mean	*9.66a*	*9.65a*		*1.39a*	*1.49a*	
Fruit yield per hectare (tons)						
Canal	44.35a	44.09a	44.22b	16.00a	15.69a	15.85b
Tube-well	39.48a	38.63a	39.06c	15.16a	14.94a	15.05c
Sewage	50.85a	50.99a	50.92a	18.86a	18.38a	18.62a
Mean	*44.89a*	*44.57a*		*16.67a*	*16.34a*	

Mean values sharing different letter(s) in a group are significantly different at $p \geq 0.05$.

Table 4: Effect of different irrigation sources on biomass production of tomato and okra.

Source of irrigation	Tomato			Okra		
	Year 2011	Year 2012	Mean	Year 2011	Year 2012	Mean
Total plant biomass on fresh weight basis (g)						
Canal	2500.2a	2595.5a	2547.9b	437.81a	416.87a	427.50b
Tube-well	2342.3a	2404.3a	2373.3c	436.37a	428.25a	432.31b
Sewage	2977.6a	3042.2a	3009.9a	634.83a	571.60a	603.21a
Mean	*2606.7a*	*2680.7a*		*503.00a*	*472.24a*	
Total plant biomass on dry weight basis (g)						
Canal	327.72a	342.88a	335.30b	75.63a	68.18a	71.91b
Tube-well	312.26a	319.98a	316.12b	83.20a	76.78a	79.99b
Sewage	396.79a	408.77a	402.78a	130.67a	125.89a	128.28a
Mean	*345.59a*	*357.21a*		*96.50a*	*90.28a*	

Mean values sharing different letter(s) in a group are significantly different at $p \geq 0.05$.

Table 5: Effect of different irrigation sources on heavy metals contents in tomato fruits and okra pods.

Source of irrigation	Tomato			Okra		
	Year 2011	Year 2012	Mean	Year 2011	Year 2012	Mean
Pb (mg kg^{-1})						
Canal	2.900a	3.123a	3.012b	0.923a	1.200a	1.413b
Tube-well	1.267a	1.173a	1.220b	1.360a	1.466a	1.061b
Sewage	16.200a	18.470a	17.335a	2.060a	3.600a	2.830a
Mean	*6.788a*	*7.588a*		*1.447a*	*2.088a*	
Ni (mg kg^{-1})						
Canal	6.867a	7.197a	7.032b	5.367a	5.700a	5.533b
Tube-well	4.100a	4.447a	4.273b	3.900a	3.977a	3.938b
Sewage	20.700a	24.973a	22.837a	8.167a	10.467a	9.316a
Mean	*10.556a*	*12.206a*		*5.836a*	*6.688a*	
Cu (mg kg^{-1})						
Canal	5.367a	6.193a	5.780b	5.180a	5.500a	5.340b
Tube-well	2.200a	1.923a	2.062c	0.913a	0.914a	0.930c
Sewage	13.800a	16.900a	15.350a	10.800a	12.400a	11.600a
Mean	*7.122a*	*8.338a*		*5.631a*	*6.271a*	
Cd (mg kg^{-1})						
Canal	1.100a	1.153a	1.126b	0.020a	0.043a	0.031b
Tube-well	0.0070a	0.008a	0.007c	0.001a	0.002a	0.002b
Sewage	1.566a	2.256a	1.911a	0.176a	0.290a	0.233a
Mean	*0.8912a*	*1.139a*		*0.066a*	*0.111a*	
Fe (mg kg^{-1})						
Canal	182.73a	194.22a	188.47b	95.00a	107.63a	101.32b
Tube-well	129.17a	136.40a	132.78c	55.47a	57.23a	56.35c
Sewage	366.73a	372.33a	369.53a	151.01a	156.72a	153.86a
Mean	*226.21a*	*234.32a*		100.49a	107.19a	
Cr (mg kg^{-1})						
Canal	1.900a	2.336a	1.916b	0.816a	0.900a	0.858b
Tube-well	0.800a	0.936a	0.885c	0.140a	0.163a	0.151c
Sewage	2.066a	2.826a	2.648a	1.303a	1.700a	1.501a
Mean	*1.734a*	*1.898a*		*0.753a*	*0.921a*	

Mean values sharing different letter(s) in a group are significantly different at $p \geq 0.05$.

recorded in pods of the plants irrigated with tube-well water (Table 5).

Heavy Metals Contents in Tomato and Okra Leaves

Among the irrigation sources, sewage water irrigated leaf samples of tomato plants contained higher Pb and Ni contents as compared to canal and tube-well water irrigated samples. While, tube-well and canal water were statistically at par with lower contents. Significantly greater Cu, Cd, Fe and Cr contents were recorded in leaves of sewage water irrigated tomato plants compared with those of irrigated with canal or tube-well water. Whereas, these contents were significantly lower in leaf samples of tube-well water irrigated plants (Table 6).

Okra plants irrigated with sewage water resulted in significantly greater Pb, Ni and Cd contents in their leaf samples than those irrigated with canal or tube-well water. Canal and tube-well water did not differ significantly and resulted in lower Pb, Ni and Cd contents. Okra leaves contained significantly higher Cu and Fe contents in sewage water irrigated plants. While, significantly lesser contents (Cu and Fe) were recorded in tube-well water irrigated plants. The maximum Cr content was found in leaves of sewage water irrigated plants, followed by canal water. These two irrigation sources were statistically similar, while the minimum Cr content was recorded in tube-well irrigated leaf samples, which was also statistically at par with canal water (Table 6).

Heavy Metals Contents in Tomato and Okra Roots

Significantly greater heavy metals contents (Pb, Ni, Cu, Cd, Fe and Cr) were recorded in roots of tomato irrigated with sewage water. Heavy metals contents were significantly lower in roots of the plants irrigated with tube-well water. All the three irrigation sources were significantly different from each other for all the heavy metals separately (Table 7).

The mean values of irrigation sources indicated that the Pb, Ni and Cd contents were significantly higher in roots of the okra plants irrigated with sewage water compared with canal or tube-well water. However, canal and tube-well water were statistically at par with lower contents (Pb, Ni and Cd). Significantly higher Cu, Fe and Cr contents were recorded in roots of the plants irrigated with sewage water. While, significantly lower Cu, Fe and Cr contents were observed in roots of the plants grown with tube-well water. The roots of the plants irrigated with canal water had intermediate levels of these metals and were statistically different from those irrigated with other two irrigation sources (Table 7).

DISCUSSION

Plant Growth

Remarkable increase in the plant height of tomato and okra was observed with the application of sewage water when compared with canal water and tube-well water application (Table 1). Similar trend was also noticed in tomato by Khan et al. (2011), who reported significantly greater plant height in waste water irrigated plants and the lowest in tube-well water grown plants. Thapliyal et al. (2011) observed taller okra plants when grown with waste water, which was possibly associated with the increase in nutrient availability due to sewage water over rain water. Similarly, greater plant height was also recorded in okra plants irrigated with sewage effluent as compared to stream water (Adewoye et al., 2010). Greater plant height with sewage water application might be associated with the presence of important plant macro- and micro-nutrients in this water.

Higher relative chlorophyll content was recorded in leaves of sewage water irrigated tomato plants compared with those of irrigated with canal and tube-well water (Table 1). This higher relative chlorophyll contents in leaves of the plants irrigated with sewage water might be associated with greater availability of macro and microelements due to sewage water application. These nutrients, when taken up by plants, improve growth and enhance leaf chlorophyll content (Zavadil, 2009; Khan et al., 2011; Balkhair et al., 2013). The present results are in line with the conclusions of Esmailian et al. (2011), Thapliyal et al. (2011) and Chalkoo et al. (2013), who recorded the maximum chlorophyll contents in leaves of *Capsicum annuum*, corn and okra, respectively, grown with waste water. Singh and Agrawal (2009) also found more chlorophyll content in leaves of okra plants grown with sewage sludge.

The leaf area of the vegetables i.e. tomato and okra was increased significantly due to the application of sewage water (Table 1) when compared with other two sources of irrigation. Tube-well water application resulted in significantly lower leaf area. The present study is closely related with the findings of Thapliyal et al. (2011) and Chalkoo et al. (2013), who recorded greater leaf area in waste water irrigated okra and sweet pepper plants, respectively, might be due to more provision of nutrients by waste water. Enhanced photosynthetic activity increases leaf area which largely depends on more nutrients and organic matter availability. Waste water is the major source of organic matter and nutrients and thus tends to enhance the leaf area (Chandra et al., 2009), leading to enhanced photosynthetic activity (Jarvis et al., 1976) and improved CO_2 fixation. Therefore, improved growth of the vegetables crops was directly linked with larger provision of nutrients constantly for longer periods from sewage water.

Table 6: Effect of different irrigation sources on heavy metals contents in tomato and okra leaves.

Source of irrigation	Tomato			Okra		
	Year 2011	Year 2012	Mean	Year 2011	Year 2012	Mean
Pb (mg kg^{-1})						
Canal	2.600a	2.707a	2.653b	1.210a	1.633a	1.756b
Tube-well	1.333a	1.400a	1.367b	1.880a	1.966a	1.588b
Sewage	10.400a	13.900a	12.150a	3.126a	4.366a	3.746a
Mean	*4.777a*	*6.002a*		*2.072a*	*2.655a*	
Ni (mg kg^{-1})						
Canal	5.067a	5.230a	5.148b	6.837a	7.667a	7.252b
Tube-well	3.400a	3.500a	3.450b	5.217a	5.313a	5.265b
Sewage	13.033a	16.150a	14.592a	10.157a	12.600a	11.378a
Mean	*7.166a*	*8.293a*		*7.403a*	*8.526a*	
Cu (mg kg^{-1})						
Canal	4.800a	5.363a	5.082b	6.500a	6.867a	6.683b
Tube-well	1.75a	1.767a	1.760c	1.933a	1.947a	1.940c
Sewage	10.833a	14.33a	12.583a	13.480a	14.767a	14.123a
Mean	*5.795a*	*7.154a*		*7.304a*	*7.860a*	
Cd (mg kg^{-1})						
Canal	0.170a	0.206a	0.188b	0.056a	0.076a	0.066b
Tube-well	0.004a	0.006a	0.005c	0.016a	0.017a	0.016b
Sewage	0.830a	0.933a	0.881a	0.213a	0.306a	0.260a
Mean	*0.334a*	*0.382a*		*0.095a*	*0.133a*	
Fe (mg kg^{-1})						
Canal	128.93a	155.53a	142.23b	125.50a	135.57a	130.53b
Tube-well	113.07a	125.83a	119.45c	109.33a	115.30a	112.32c
Sewage	264.50a	267.03a	265.77a	193.90a	204.17a	199.03a
Mean	*169.68a*	*181.95a*		*142.91a*	*151.68a*	
Cr (mg kg^{-1})						
Canal	0.900a	0.901a	0.900b	1.260a	1.666a	1.463ab
Tube-well	0.566a	0.650a	0.608c	0.426a	0.450a	0.438b
Sewage	1.516b	2.100a	1.808a	2.176a	2.800a	2.4883a
Mean	*0.994a*	*1.216a*		*1.287a*	*1.638a*	

Mean values sharing different letter(s) in a group are significantly different at $p \geq 0.05$.

Table 7: Effect of different irrigation sources on heavy metals contents in tomato and okra roots.

Source of irrigation	Tomato			Okra		
	Year 2011	Year 2012	Mean	Year 2011	Year 2012	Mean
Pb (mg kg^{-1})						
Canal	1.700a	2.106a	1.903b	2.816a	2.866a	2.841b
Tube-well	0.216a	0.296a	0.256c	2.120a	2.266a	2.193b
Sewage	5.133a	6.566a	5.850a	4.533a	5.533a	5.033a
Mean	*2.350a*	*2.990a*		*3.156a*	*3.555a*	
Ni (mg kg^{-1})						
Canal	3.800a	4.160a	3.980b	8.457a	8.933a	8.695b
Tube-well	2.333a	2.483a	2.408c	6.203a	6.400a	6.302b
Sewage	10.667a	12.533a	11.600a	12.933a	17.467a	15.200a
Mean	*5.600a*	*6.392a*		*9.198a*	*10.933a*	
Cu (mg kg^{-1})						
Canal	3.700a	4.763a	4.232b	7.403a	7.733a	7.568b
Tube-well	1.000a	1.160a	1.080c	2.860a	2.833a	2.847c
Sewage	9.867	11.667a	10.767a	15.960a	17.067a	16.513a
Mean	*4.855a*	*5.863a*		*8.741a*	*9.211a*	
Cd (mg kg^{-1})						
Canal	0.110a	0.113a	0.111b	0.153a	0.186a	0.170b
Tube-well	0.001a	0.002a	0.001c	0.025a	0.026a	0.025b
Sewage	0.630a	0.733a	0.681a	1.416a	2.266a	1.841a
Mean	*0.248a*	*0.281a*		*0.531a*	*0.826a*	
Fe (mg kg^{-1})						
Canal	105.13a	115.67a	1110.40b	229.00a	245.63a	237.32b
Tube-well	85.57a	95.27a	90.42c	135.40a	139.57a	137.48c
Sewage	152.10a	155.73a	153.92a	308.63a	307.63a	308.13a
Mean	*114.27a*	*122.22a*		*224.34a*	*230.94a*	
Cr (mg kg^{-1})						
Canal	0.400a	0.507a	0.453b	1.850a	2.300a	2.075b
Tube-well	0.100a	0.233a	0.166c	0.720a	0.733a	0.726c
Sewage	0.800a	0.883a	0.841a	3.343a	3.533a	3.438a
Mean	*0.433a*	*0.5412a*		*1.971a*	*2.188a*	

Mean values sharing different letter(s) in a group are significantly different at $p \geq 0.05$.

Yield and its Components

Various sources of irrigation used had profound influence on number of fruits. Significantly higher number of tomato fruits and okra pods were observed in the sewage water irrigated plants than those of canal and tube-well water irrigated ones (Table 2). Fruit length of tomato varied significantly due to irrigation with different sources of water and was in order: sewage water > canal water > tube-well water. Okra pod length was also significantly greater in plants which were irrigated with sewage water, preceded by those irrigated with canal water. Similarly, okra pod diameter was greater in sewage water grown plants, followed by those with canal water. However, in the present study tomato fruit diameter was not affected by the irrigation sources. The present results are in line with Thapliyal et al. (2011) and Chalkoo et al. (2013), who counted higher number of fruits per plant and greater fruit length in okra and sweet pepper, respectively, irrigated with waste water. Adewoye et al. (2010) also recorded higher number of pods when plants were grown with sewage effluent as compared to stream water.

In the present study, fresh and dry weights of individual fruit and yield per hectare were significantly increased in tomato and okra by sewage water application compared with canal and tube-well water applications. The increased fruit yield of tomato plants grown with sewage water was also obtained by Önal et al. (2003), Topcuoğlu et al. (2003) and Özyazıcı (2013). Application of waste water also increased the production of peppers (Chalkoo et al., 2013). Similarly, Adewoye et al. (2010) also recorded higher yield of okra grown with sewage effluents compared with stream water. Greater yield of sweet pepper and eggplant was obtained when waste water was used as irrigation source compared with fresh water (Papadopoulos et al., 2013). Application of waste water tends to enhance total N, total C and soil microbial activity and as a result, the nutrient availability is increased to plants (Friedel et al., 2000; Ramirez-Fuentes et al., 2002; Mekki et al., 2006). Waste water not only contained greater quantity of macronutrients, but also had higher contents of micronutrients essential for proper plant growth (Angin et al., 2005). Thus, use of waste water improves the fertility level of soil and decreases the usage of fertilizers and finally improves the economic benefits to the farmers.

Biomass Production (on fresh and dry weights basis)

Fresh and dry biomass production of vegetables was significantly affected due to various sources of irrigation (Table 3). This increase was possibly due more availability of nutritious elements to the plants irrigated with sewage water. Khan et al. (2011) documented higher fresh and dry biomass in waste water irrigated tomato plants than fresh water irrigated ones.

Dry matter of tomato plant was also increased with the application of sewage water (Önal et al., 2003; Singh and Agrawal, 2009; Balkhair et al., 2013). Thapliyal et al. (2011) also reported greater total fresh or dry biomass of okra plants grown with waste water compared to rain water. Irrigating crops with waste water enhances biomass production as it provides bigger quantity of organic and inorganic components important for excellent growth and development of plants (Ullah et al., 2011; Gosh et al., 2012).

Heavy Metals Accumulation in Tomato and Okra

Different water sources used for irrigation significantly influenced the heavy metals contents of tomato fruits and okra pod, leaves and roots. Greater values of heavy metals contents (Pb, Ni, Cu, Cd, Fe and Cr) were detected in sewage water irrigated root, leaf and fruit samples of tomato, followed by canal water, whereas, the lesser in tube-well water irrigated ones (Table 5, 6 and 7). This also demonstrated that the plants grown on infected soils accumulated more and those grown on unpolluted soils contained lower amounts of heavy metals (Hooda et al., 1997; Pinochet et al., 1999; Butt et al., 2005). Therefore, the soils irrigated with sewage water continuously for longer periods can buildup higher metals contents and resultantly higher uptake and accumulation in different parts of the vegetables grown on these soils. The present results are in agreement with the conclusions of Lone et al. (2003) and Pathak et al. (2012), who detected higher Pb, Ni, Cu, Cd, Fe and Cr contents in pods from sewage water irrigated okra plants compared with those of tube-well water irrigated ones. The present results are also in line with the findings of Randhawa et al. (2014), who recorded higher Pb and Cd contents and Farid (2003), who observed higher Pb content in pods of okra irrigated with sewage water. Onianwa et al. (2001), Yusuf et al. (2003) and Chunilall et al. (2004) found that Ni and Cu contents present in soil can be taken up by the vegetables. Pods from sewage and canal irrigated okra plants had more content of Cd. This might be due to the reason that sewage and canal waters and the soils irrigated with these waters contained more Cd content, resulting in increased Cd accumulation in pod of the plants grown on these contaminated soils. Higher Fe and Cr contents in sewage water irrigated okra plant parts indicate the occurrence of higher amount of these heavy metals in sewage water and soil. Khan et al. (2013) recorded higher Cr content in pod samples of okra irrigated with waste water. The Cr content in okra pods of the present study (Table 5) was several folds higher than the values stated by Sujatha et al. (2013).

Higher Pb and Cd concentrations in sewage water irrigated leaf samples might be attributed due to different industrial effluents operating near the experimental area. Industrial wastes and effluents are drained into canals, which contain heavy metals, therefore more Pb and Cd were detected in canal irrigated leaf samples. Sewage water contained domestic as well as industrial effluents. Rolli (2014) also detected higher Cu and Ni contents above safer limits in leaves, roots and fruits of tomato plants irrigated with sewage water. These results are in line with the conclusions of Khan et al. (2011), who found higher Pb, Ni, Cu and Fe contents in leaves and fruits of tomato plants grown with waste water. Butt et al. (2005) and Randhawa et al. (2014) also observed higher Pb, Ni, Cu and Cd contents in tomato and brinjal fruit samples, respectively irrigated with sewage water. Similarly, Yadav et al. (2013) reported greater Pb, Ni, Cu, Cd and Fe contents in tomato fruits grown with waste water. Accumulation of Cu in waste water-irrigated tomato fruits were also found higher and above the safer limits (Liu et al., 2005; Singh et al., 2010). Cd content detected in the present study (Table 5) is in line with those reported by Cui et al. (2004). Industrial emission, discharge of lead storage batteries, paints or pigments and sewage water are the main sources of Pb. The present results are in close conformity of Arora et al. (2008), who reported higher metals accumulation in waste water irrigated vegetables compared with those of irrigated with fresh water. The differences in metals contents of tomato fruits in the present study and previous studies might be due to the physico-chemical properties of soil, different nature of plants and their metals absorption capacities. Different soil factors like pH, cation exchange capacity, organic matter, texture and clay content affect the heavy metals accumulation (Overesch et al., 2007). The heavy metals accumulation is also affected by plants parts and age of the plant (Liu et al., 2007). Khan et al. (2008) also reported higher Cr content in leaves of tomato when irrigated with waste water. Greater Cr accumulation in leaves was possibly associated with higher contents of Cr in sewage water as well as the soil. Excessive use of fertilizers, irrigation with waste water and use of soils polluted with urban and industrial effluents are the major factors responsible for increasing Cr content in soil and crops. The current results are in agreement with the conclusions of Perveen et al. (2011), who reported higher Fe content in vegetables irrigated with sewage water, which was above the safe limits. They further stated that Fe content was higher in leaves compared with edible portions. The higher metals contents in sewage water irrigated tomato roots indicate the presence of higher levels of these metals in soil and sewage water.

The crops grown with polluted water accumulate more heavy metals contents than those grown with unpolluted water (Butt et al., 2005). The vegetables irrigated with sewage water can enhance the transfer of heavy metals contents to edible parts. Increased Pb, Cd, Fe and Cr contents in canal irrigated tomato fruits might be due to industrial and sewage effluents drained in canal water which contains heavy metals and its use for irrigation purposes. Cd is highly mobile, easily absorbed by plants via roots and then transferred to aerial parts. Thus, roots of eggplant contained increased Cd content when plants were irrigated with waste water (Bigdeli and Seilsepour, 2008). Cd content detected in the present study (Table 7) is also in line with those reported by Cui et al. (2004).

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