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Assessing Vegetable Growth and Yield Response to Graywater Irrigation

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ABSTRACT

The impacts of graywater irrigation on soil properties and vegetable yields were assessed through a three-year field experiment for Bell Pepper, Chile, and Tomato in El Paso, Texas in the United States. Two irrigation treatments including freshwater (well water and sand filter effluent) and graywater (laundry water) with three replications were utilized in the study. Duncan's multiple range test at the significance level of 0.05 was used to test changes in soil properties including soil pH, salinity, and sodicity, and mean differences in vegetable growth and yields in terms of fruit height, fruit count, weight, and fruit sizes under freshwater and graywater irrigation treatments. The statistical analysis suggests that no evident salt accumulations or changes in salinity and sodicity were observed at the soil surface in the depth of 0-15cm, while soil pH is increased significantly with graywater irrigation. The growth and yield of Bell pepper and Chile under graywater irrigation tend to increase as compared to freshwater irrigation although the results for the third year were not significant. No yield decreases regarding fruit weight, fruit counts and fruit sizes were observed for all vegetables. It can be concluded from the experimental research that the graywater has shown promising potential as an alternative water supply for vegetable production in the El Paso region, Texas.

Keywords: Bell pepper, Chile, Tomato, Graywater, Freshwater, Height, Yield, Soil Salinity, Soil properties

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1 Introduction

It is becoming increasingly difficult to meet growing demands with limited freshwater resources in the Southwestern United States and other similar arid and semi-arid regions. In this arid region, the rapid urbanization has resulted in a significant increase in freshwater demands for potable and irrigation uses. Extending water supplies, whether from the river, aquifer or water treatment plant is essential for the Rio Grande basin, where rapid population growth, high agricultural irrigation usage, water salinity, water quality deterioration is adding stresses to already limited water resources. Discovering safe, beneficial, and economically feasible strategies to utilize non-traditional water sources such as graywater, reclaimed wastewater and salty groundwater will benefit the basin. The long-term goal is to maintain agricultural productivity and urban landscapes with alternative irrigation sources to conserve the region's depletable aquifers. Use of non-potable alternative water sources such as graywater and reclaimed wastewaters to irrigate suitable agricultural crops including bioenergy crops may be a productive and efficient method of managing this water and would lessen the demand on potable supplies.

Municipal wastewater reuse in Texas was about 720 million liters per day in 1998 and is projected to increase to 27% of the total water demand by 2050 (TCEQ, 2005). Reclamation from centralized wastewater treatment is primarily used for golf course irrigation, manufacturing, and cooling towers. In El Paso, advanced treated water was also used to recharge the Hueco Bolson aquifer (Sheng, 2005). There is potential to increase wastewater reuse to approach countries such as Israel, which reuses at least 60 percent of its wastewater. Graywater (wastewater from showers, basins, laundry, and kitchen) recycling has a great potential because it comprises up to 68% of total domestic wastewater (Emmerson, 1998). And the potential to reduce urban potable water demand is by up to 30-70% (Radcliffe, 2003). The use of decentralized wastewater streams such as graywater reduces sewage flows and the demands on centralized wastewater treatment plants and distribution systems because the need for graywater reclamation is often close to the source. Graywater is also drought-proof water resource that increases with economic and population growth. As some graywater constituents are nitrogen and phosphorus, they may be beneficial to soil/plant systems.

Because graywater is a dilute form of wastewater, there is always the concern of harmful chemical and biological constituents that may impact human health and the integrity of potable groundwater supplies. Fecal coliform counts have been reported to be as high as 6,000 colonies forming units per 100 mL in shower water (Rose et al., 1991). The use of personal care products, pharmaceuticals, and surfactants may also increase the presence of no conventional contaminants, which is of growing concern (Wiel-Shafran et al., 2005; Wiel-Shafran et al., 2006). However, the main contaminant in graywater is the potential concentration of salts, if supplies are used for irrigation. In arid regions, many soils are susceptible to salt damage, which renders land infertile and ultimately unproductive. Reuse of salty graywater as an alternative water supply may quickly damage soils that are susceptible to salinity and sodicity. Salt accumulation may also affect plant survival and production (Gawad et al., 2005). Most plants express salt damage at 3,000 ppm TDS and cannot survive beyond 5,000 ppm TDS (Toenniessen, 1984).

Graywater has been applied widely in landscape irrigation, groundwater recharge and crop irrigation and other areas. Consequently, many studies related to the effects of graywater on plant growth, yield and soil properties have been conducted and reported worldwide over the decades. Some research results showed that graywater irrigation increase plant growth and yield without any effect on the quality of the crops. (Day et al., 1981; Rusan et al., 2007; Misra et al., 2009). However, some research results show the opposite. Finely et al. (2008) found no significant difference in plant growth observed between the graywater and tap water on lettuce and carrots. Mzini (2013) found that graywater irrigation increases the yield of some vegetables such as cabbage and onions, while others such as lettuce, spinach, and carrots do not respond significantly in terms of yield to the graywater irrigation.

This study explored the potential for safe and beneficial use of graywater for irrigation of vegetable plants. The impacts of graywater as an irrigation water supply were compared with freshwater (salty well water in first and second years and sand filter effluent from El Paso Water Utility in the third year) for vegetable production. The preliminary research reports suggest that the reuse of graywater (laundry water) for irrigation in the El Paso area may be beneficial even for salt sensitive plants like vegetables (Assadian et al., 2006; Sheng et al., 2007). This paper presents findings on the impacts of graywater irrigation on vegetable growth, yield and soil properties from a field experiment in comparison with freshwater. The specific objectives of the experimental research were: to evaluate the response of vegetable growth, quality, and yield to graywater irrigation; to assess the potential effects of graywater irrigation on soil salinity, sodicity and soil nutrition along the time. A detailed statistical analysis has been carried out to address the issues of research questions that related to graywater irrigation as compared to traditional freshwater irrigation, and the results and conclusions are presented in the following sections of the paper.

2 Materials and Methods

2.1 Experimental design

This field study was conducted at Rogelio Sanchez, Texas State Prison in El Paso, Texas, the United States. The soil was loamy sand underlain by shallow to deep layers of caliche (calcium carbonate) and belonging to the Hueco Association (Coarse-loamy, mixed, thermic Petrocalcic Paleargids)-Wink (Coarse-loamy, mixed, thermic Typic Calciorthids). Top soil was collected from mesquite hummocks and placed on plots to a depth of about 15cm. Furrows were trenched around each row. Row spacing was 1 m with nine 6m long rows in each plot. In this experiment, laundry water and fresh water were treatments. The experimental design was a split plot with water type as main plots and vegetable crops as subplots with three replications in an incomplete randomized block design (Figure 1).

2.2 Irrigation water and soils

Two types of water are available at the experimental site for study: laundry water from the prison is used as graywater irrigation, well water from neighboring well and sand filter effluent from El Paso Water Utility are used as the freshwater irrigation in this study. In first and second years, the well water was used as the freshwater irrigation source, while the sand filter effluent was used as the freshwater irrigation in the third year due to the availability of well water. The chemical properties of the irrigation waters are given in Table 1. The graywater (laundry water) was slightly alkaline with a pH of 8.19, non-saline with an EC of 1.54 dSm^{-1}, but sodic with an SAR of 16. Recall that irrigation water is considered saline when EC approaches 4 $dS\ m^{-1}$ and sodic when the SAR approaches 13. Sodicity is often observed, but not necessarily problematic when total salt loads and Ca are in low concentrations. Laundry water phosphates were detectable and averaged 8.29 $mg\ L^{-1}$. Phosphorus concentrations were greater than the 2.4 $mg\ L^{-1}$ reported for a large college with multiple waste streams contributing to graywater (Al-Jayyousi, 2003). Laundry water was less saline but more sodic and alkaline than well water. Well water NO_3 was about 4.4 $mg\ L^{-1}$. Phosphates were not detected. Well water rather than laundry water had greater concentrations of Cl and SO_4 (Table 1).

The low salt constituents in laundry water were likely due to on-site water softening of El Paso City tap water at the prison. Analysis of water from a drinking fountain at the prison indicated that on-site water treatment at the prison had produced water similar in quality to deionized water. The chemical quality of laundry water was consistent during the experiment. The quality of laundry water regarding salinity was better than that of well water. However, the overall quality of both laundry water and well water did not approach that of El Paso City's reclaimed water from sand filtration, despite the lower salinity found in laundry water.

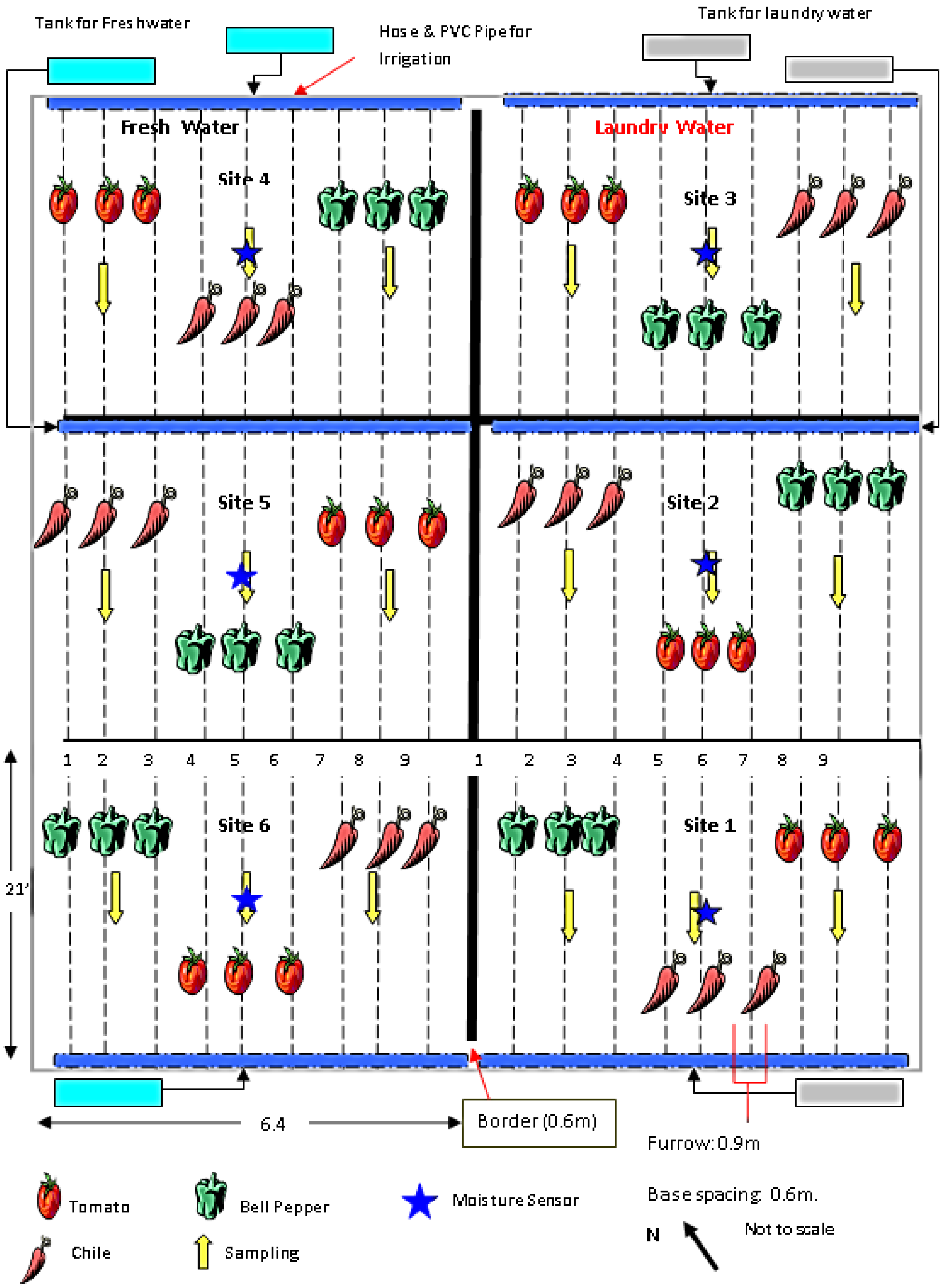

Figure 1. Plot design for evaluation of the potential of graywater (laundry water) and freshwater (well water and sand filter effluent) as an irrigation supply for Bell pepper, Chile (Jalapeño) and Tomato production.

Table 1 Chemical characterization of graywater (laundry water) and freshwater (well water and sand filter effluent) used to irrigate the vegetable field.

Chemical Parameter	Graywater (Laundry Water)	Fresh Water	
		Well Water	Sand Filter Effluent
pH	8.19	7.72	7.27
EC[1] (dS m^{-1})	1.54	2.61	1.83
Available Ca (mg L^{-1})	20.4	120	59
Available Mg (mg L^{-1})	5.72	25.3	16
Available Na (mg L^{-1})	320	438	264
SAR[2]	16.0	9.44	7.8
Cl (mg L^{-1})	139	420	40
NO_3 (mg L^{-1})	3.44	4.37	15.6
PO_4 (mg L^{-1})	8.29	0.00	2.87
SO_4 (mg L^{-1})	151	675	164.6

[1] EC, Electrical Conductivity [2] SAR, Sodium Adsorption Ratio

Each block (as shown in Figure 1) was irrigated three times a week with either 946 or 1892 liter/plot (0.0125 or 0.25mm/acre) from April 16 to September 15. A total of 1075mm of laundry water or freshwater were applied to plots. The El Paso rainfall is typically about 200 mm during the growing season. Annual pan evaporation is approximately 2500mm, of which over 1750mm is during the growing season. The original sandy soil was moderately alkaline (pH of 8.3), but not saline (EC< 4 dSm-1) before irrigation. Total N, NO_3-N, and NH_4-N were at low concentrations; the soil was considered N deficient. The chemical characteristics of the soil before the vegetable planting and irrigation are shown in Table 2.

Table 2 The chemical characteristics soil prior to experiment at Rogelio Sanchez State Prison, El Paso, Texas.

Chemical Parameter	**Loamy sand prior to experiment**
pH	8.3
EC[1] (dS m^{-1})	1.02
Available Ca (mg L^{-1})	98.6
Available Mg (mg L^{-1})	31.4
Available Na (mg L^{-1})	115
SAR[2]	12.4
TKN (mg kg^{-1})	335.9
NH_4-N (mg kg^{-1})	4.8
NO_3-N (mg kg^{-1})	7.2
PO_4 (mg kg^{-1})	23.6

[1] EC, Electrical Conductivity [2] SAR, Sodium Adsorption Ratio

2.3 Planting of Vegetables

Each vegetable crop was planted in three consecutive rows per block. Vegetable seedlings were purchased from a local nursery and transplanted to plots on May 3 of the year. Two seedlings were planted together every 60cm on beds after organic mulch was placed in the planting hole to ensure sufficient soil moisture. Seedlings were thinned to one plant every 60 cm on May 9 of the first year. The same procedure was followed, but the Bell pepper and Chile were eaten by rodents in the second year. Cherry tomato was transplanted to replace missing beef tomato (large tomato). Seedlings were thinned to one plant every 90 cm in 17th of May. Due to the differences of vegetables after replacement by other plants, only soil property analysis was considered in this study for the second year, the growth and yield of replacement vegetables (cherry tomato and large tomato) for the second year were not considered in the analysis of this paper. In the third year, the vegetable seedlings (Bell Pepper, Anaheim Chile (Jalapeño), and Tomato) were purchased from a local nursery and transplanted to plots on April 16. Two seedlings were planted together every 60 cm on beds after organic mulch was placed in the planting hole to ensure sufficient soil moisture.

2.4 Sampling and data collection

Soil moisture

Echo™ soil moisture sensors were placed in each plot. Moisture sensors were placed 15, 30, and 45 cm below the surface before planting. Three moisture sensors were placed at each of three depths and connected to above-ground data loggers. Sensors were set up to collect data every 15 minutes.

Soil sampling

Soil samples were collected from the top 15 cm before bed formation before the experiment to establish baseline chemical characterization of the soil. Before field preparations, laundry, drinking, and well waters were also collected at the source and analyzed to characterize salts, nutrients, and metal concentrations. After planting, irrigation water samples were collected at the field from tanks and surface soil (0-15 cm depth) was collected from a designated site for each vegetable crop in each plot on May 23rd , June 24th , July 22nd , August 26th , and October 4th or 20, 52, 80, 115, and155 days after planting (DAP) in the first year, respectively. Subsurface soil samples from the 15 to 60 cm depths were also collected on October 4.

Irrigation water samples were collected at the field from tanks and surface soil (0-6 in depth) was collected from designated sites for each plot on June 2nd, July 11th, August 4th, September 8th, or 30, 69, 93, 128 and 160 days after planting (DAP) on October 10th in the second year, respectively. The subsurface soil was also collected at the end of the season at greater depths, 15 to 30 cm, 30 to 45 and up to cliché layer.

Irrigation water samples were collected at the field from tanks and surface soil (0 to 15 cm depth) was collected from designated sites for each plot on April 9th, May 14th, June 18th, June 26th, July 17th and August 15th or 7, 28, 62, 70, 91, and 119 days after planting (DAP) in the third year, respectively. The subsurface soil was also collected at the end of the season (September 17) at greater depths, 0 to 15 cm, 15 to 30, 30 to 45, and 45 to 60 cm where the cliché layer is located.

Water sampling

All water samples were filtered for chemical analyses. Initial analytical determinations for water samples included pH, Electric Conductivity (EC), soluble calcium (Ca), magnesium (Mg), and sodium (Na), copper (Cu), iron (Fe), zinc (Zn), and phosphorus (P). Water samples were also analyzed for total and free chlorine (Cl), hardness, and alkalinity using Hach™ Aquachek water quality strips. Once irrigation began, laundry and well waters samples collected from the field were analyzed for pH, EC, soluble Ca, Mg, and Na, free chlorine, and phosphate (PO4) using standard water methods (US Salinity Laboratory Staff, 1954). Analytical determinations for soil included pH, EC (electrical conductivity), soluble calcium (Ca), magnesium (Mg), and sodium (Na), total Kjeldahl nitrogen (TKN), ammonium N, nitrate N, and available phosphorus (P) using standards soil methods (Sparks, 1996).

Vegetable harvest

Plant mortality was counted on May 9 of the first year and checked for infection of the curly top virus on June 10 in all plots. Three plants adjacent to designated soil sampling sites were measured for plant height on May 23, June 2, and June 24 or 21, 30 and 52 DAP, respectively. Fruit yields were determined from four harvests from the same plants in each plot. The mature fruit was harvested, counted, and weighed immediately after harvest July 22, August 16, Sept 1, and October 4 or 80, 105, 121, and 155 DAP in the first year, respectively.

Cherry and large tomatoes were harvested at different times, and similar procedures are followed, but the statistical analysis is not included in this paper due to the inconsistent types of vegetables as in the first and second year. Bell pepper, Chile, and Tomato were harvested at the same time from each sample site in the third year. Vegetables were harvested on July 9, July 24, August 6, August 20, and September 4 or 83, 98, 110, 124, and 138 DAP, respectively. Rotten (over-ripen) vegetables were not harvested. Immediately after harvesting, vegetables were taken to the laboratory for counting and weighing.

2.5 Statistical Analysis

The effects of graywater irrigation on the chemical characteristics of soil and vegetable yield function were analyzed using Statistical Analysis Software (SAS, 2006) and delineating treatment effects at the 0.05 significance level of probability using Duncan's multiple range tests.

3 Results and Discussion

3.1 Irrigation water

Water delivery was one of the most challenging issues at the prison test site. Security prevented the construction of a continuous pipe system from the laundry trap inside the prison to the field test site outside of the prison. As a consequence, water was pumped and transferred from one mobile reservoir to a stationary one. The 950-liter capacity of the stationary water tanks dictated irrigation volumes at application. In most cases, the application of irrigation water and large rainfall events were detected by top moisture sensors (15 cm below the land surface). Soil moisture was typically smaller than 25% on a volumetric basis.

Table 3. Average irrigation water chemical properties sampled at different days of the irrigation season

pH		EC(dS m^{-1})		SAR	
Well water	Graywater	Well water	Graywater	Well water	Graywater
7.29	8.14	2.57	1.28	12.06	13.96

Higher moisture was observed in the effective root zone than in deeper layers. Surface soil moisture was also slightly variable among blocks. These differences were attributed to inconsistent soil texture and underlying cliché layer. The lack of recorded soil moisture changes from sensors at the 45cm depth indicated that the potential of groundwater contamination from graywater irrigation was minimal because the majority of irrigated water were consumed through evapotranspiration and deep groundwater surface. Table 3 shows the average chemical parameters of the irrigation water that analyzed in the different days of planting (DOP) in the first year of the experiment. As can be seen from the Table 3, the water salinity of well water is higher than that of graywater throughout the season.

3.2 Soil Properties

The soil properties were analyzed in the entire experimental plot regardless of the type of vegetables grown since statistical tests for each year showed that the types of vegetables planted do not significantly affect the soil properties. Hence, the soil property analysis is based on the entire plot and is not differentiated between the vegetables in this study.

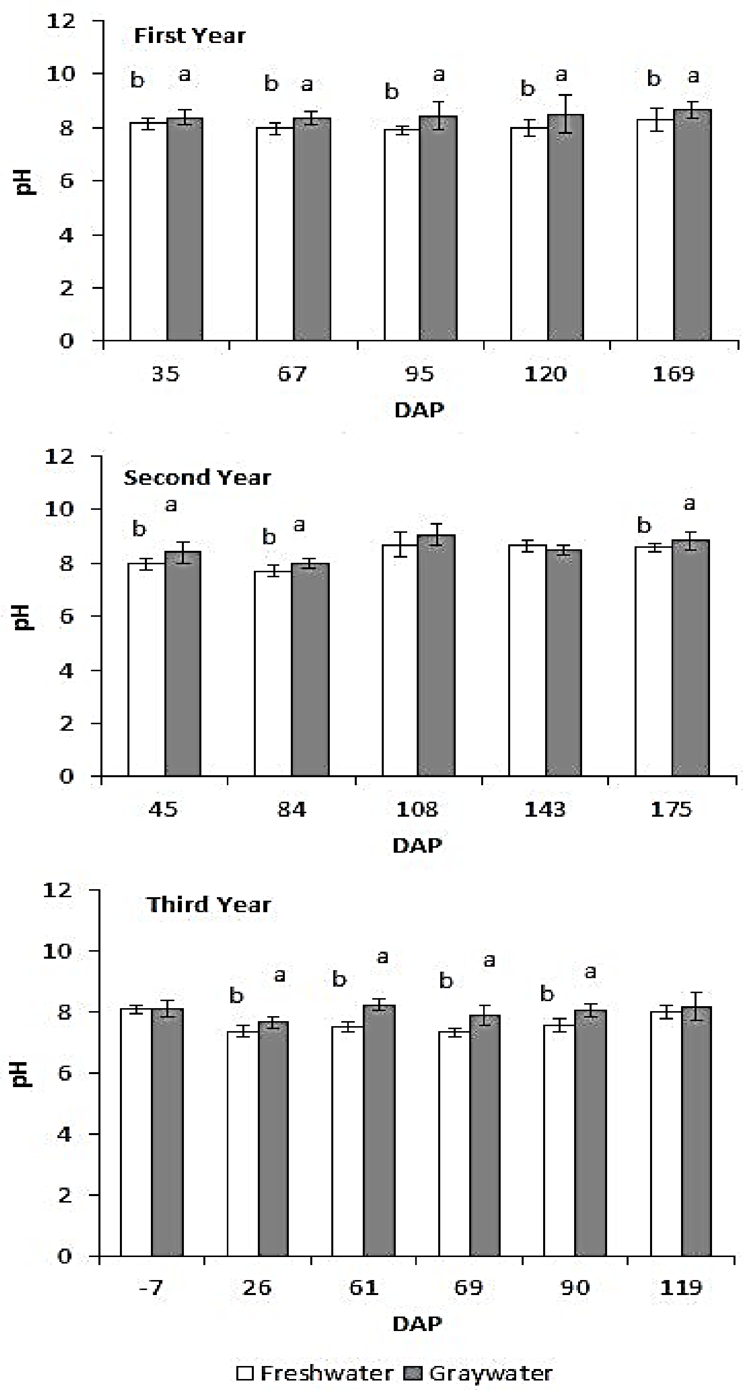

Figure 2. Changes in soil pH values at top soil (0- 15cm) for different days after planting (DAP) for all years under graywater irrigation

Soil pH

Figure 2 shows the effects of graywater irrigation on soil pH values at the top soil (0-15cm below the soil surface) at different planting dates for all years. The statistical test of pH values at the top soil (0-15cm) suggest that graywater irrigation has a significant effect (p=0.05) on the pH values of the soil at all days after planting except several planting dates in second and third years. In general, soil pH values irrigated with graywater were significantly greater than those of irrigated with freshwater in the depths 0-15 cm. In July and August of the second year, the heavy rainfalls bring pH up to 9.1 and 8.7 for graywater and well water respectively and affect the rate of change in both graywater and freshwater.

Most of the previous research results are consistent in evaluating graywater impact on soil pH values. Pinto et al. (2010) reported that irrigating silver beet with 100% graywater resulted in a significant ($p < 0.05$) increase in soil pH when compared with the freshwater. Qishlaqi et al. (2008) suggested the increase in soil pH when irrigated with graywater. However, Mzini (2013) reported that no significant difference observed in pH throughout the soil profile of 0 to 90 cm under different treatment of graywater irrigation. Some researchers find the opposite. For example, Wiel-Shafran et al. (2006) reported that pH of soils irrigated with graywater become significantly lower that of the freshwater irrigated soils due to the probability of enhanced bacterial activities such as respiration. The different research results could be induced by the chemical properties of graywater that might have lower pH values in irrigation water itself.

Soil salinity and sodicity

Figure 3 shows the effects of two irrigation treatments on the soil salinity at the top soil (0-15cm). The soil salinity is described in terms of electrical conductivity (EC) in this study. In first and second years, the soil irrigated with salty well water tends to have significantly higher EC in all after planting dates at p=0.05 significance level. In the third year, the graywater irrigation increases soil salinity significantly on the day of planting dates of 26 and 119 although other dates show no significant increase there is increasing tendency. The difference can be attributed to the salinity of freshwater used in a different year. In first and second years, the salty well water (as shown in Table 1) was used as fresh water, which has higher EC than graywater. In the third year, the El Paso City's reclaimed water from sand filtration was used as freshwater which is of lower EC value than graywater. In July and August of second year, the heavy rainfalls flushed down the soil salinity and bring down the EC value of the soil very low, 0.53 and 0.32 ds m^{-1} respectively for well water and graywater at DAP of 143.

Figure 3 also illustrates the effects of graywater irrigation on sodium absorption ratio (SAR) of soil depths at 0-15cm. The trends in SAR values in all years were similar to salinity, but no significant impacts were observed in all days of planting in all years except DAP of 61 and 119 of the third year that the SAR of soil increased significantly ($p<0.05$) with irrigation of graywater. This trend shows that dominant salts in the study site are probably sodium salts. Apart from the end of the third year, none of the soils exceeded the SAR limit of 13 to be considered as sodic (U.S. Salinity Laboratory Staff, 1954). There is no conclusive suggestion that graywater irrigation affects the SAR values at the top soil during and at the end of growing season.

Similar results are also documented in the literature. Patel et al. (2003) reported that the salt buildup does occur in the later part of the growing season under sub-irrigation with brackish water. They suggested that the crops could be grown using brackish water of salinities up to 9 ds m^{-1} provided the water be applied using sub-irrigation. The authors also concluded that green peppers could be successfully grown in nonsaline soils under sub-irrigation using brackish waters having EC values as high as 9 ds m^{-1}. However, the level of salt accumulation could be different in the context of rainfall and irrigation strategy. It should be noted that large rainfall events during monsoon season in the second year at the experimental site have helped to flush out salts from the top soil and increased cotton growth as well as lint yield. Therefore, the results for soil salinity and impacts of water type from this study may be altered by those heavy rainfall events. It is recommended that additional experimental study is conducted to evaluate long-term impacts of water type on soil salinity and vegetable yield.

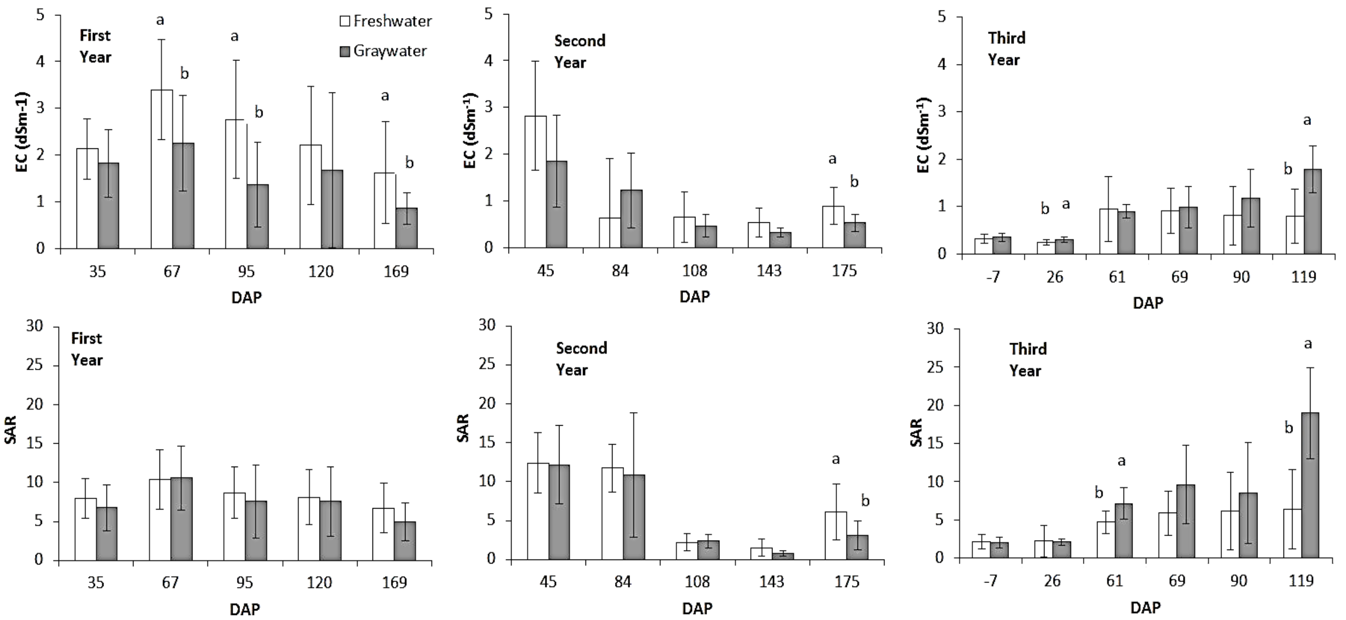

Figure 3. Changes in soil electrical conductivity (EC) and sodium absorption ratio (SAR) at top soil (0- 15cm) for different days after planting (DAP) under graywater irrigation

3.3 Vegetable growth

Table 4 and Table 5 showed the effects of graywater irrigation on the vegetable growth. At the different days of planting measurements of vegetable heights in first and third years were used to evaluate the impacts. In the first year, the vegetable heights for Bell Pepper, Chile, and Tomato were measured three times at the days after planting of 27, 45, and 59 (as shown in Table 4). The analysis for the second year is not included in this paper since other vegetables (cherry tomato and large tomato) have been transplanted after the rodent had eaten the previously planted Bell Pepper, Chile, and Tomato. In the third year, the heights are measured at DAP of 21, 44, 62, 97 respectively for Bell Pepper, Chile, and Tomato (as shown in Table 5). The statistical analysis showed that there is no tendency in mean height increase since the statistical tests are not significant at p=0.05 significance level both years. Only the analysis of samples collected in days after planting 59 in the first year indicated that the Bell Pepper irrigated with graywater resulted in significantly higher vegetable height as compared to freshwater irrigation.

It is not conclusive from the experimental research that the graywater irrigation tends to have positive effects on the vegetable growth as compared to freshwater irrigation. Similar results were also reported in other studies. For example, Pinto et al. (2010) reported no significant difference in silver beet growth over 60 days when irrigated with freshwater or graywater. Finely et al. (2008) found no significant difference in plant growth observed between the graywater and tap water on lettuce and carrots. Kiziloglu et al. (2008) reported that the nutrient contained in wastewater might increase plant growth, but long-term effects are largely unknown. Hence, more studies will be needed to reach a distinct conclusion as the graywater quality varies immensely, and the use of various wastewaters for irrigation may have significantly different effects on plant growth. Plant growth in response to graywater irrigation appears to be dependent on the type of crop and nutrient content of the irrigation water.

Table 4. Effects of graywater on vegetable height in the first year (Bold numbers are statistically different in means at p=0.05)

Crop	Day of Planting	Water	Sample Size	Mean Height (cm)
Bell Pepper	27	Freshwater	11	9.4 a
		Graywater	11	9.9 a
	45	Freshwater	11	12.2 a
		Graywater	11	12.2 a
	59	Freshwater	10	**15.2 b**
		Graywater	11	**19.3 a**
Chile	27	Freshwater	11	10.2 a
		Graywater	11	11.9 a
	45	Freshwater	11	20.1 a
		Graywater	11	20.0 a
	59	Freshwater	11	26.2 a
		Graywater	11	28.3 a
Tomato	27	Freshwater	12	29.2 a
		Graywater	12	29.5 a
	45	Freshwater	12	45.5 a
		Graywater	12	43.6 a
	59	Freshwater	12	52.2 a
		Graywater	8	53.8 a

3.4 Vegetable yield

The effects of graywater irrigation on vegetable weight, the number of fruits per plant and the fruit sizes for different vegetable types at different days after planting for first and third years were plotted in Figure 4 and Figure 5 respectively. In general, the vegetable weight, number of fruits per plants and the fruit sizes showed increasing trends under graywater irrigation in terms of the sample mean at each stage although no significant impacts were concluded statistically for the third year. In the first year, Bell Pepper weight and number of fruits per plant increased significantly under graywater irrigation as compared to freshwater irrigation when the DAP greater than 105 days. The same trend was observed for Chile in the first year indicating that irrigated with graywater increase the Chile yield significantly compared to freshwater irrigation. However, the graywater irrigation of Tomato does not have significant impacts on the plant weight, fruit counts and fruit sizes in all samples that measured in different growing stages except fruit counts showed a significant increase at DAP of 121 in the first year (as shown in Figure 4).

Table 5. Effects of graywater on vegetable height in the third year (Bold numbers are statistically different in means at p=0.05)

Crop	Day of Planting	Water	Sample Size	Mean Height (cm)
Bell Pepper	21	Freshwater	15	10.2 a
		Graywater	15	8.5 a
	44	Freshwater	13	12.5 a
		Graywater	15	13.0 a
	62	Freshwater	13	17.4 a
		Graywater	13	17.7 a
	97	Freshwater	9	32.5 a
		Graywater	9	32.7 a
Chile	21	Freshwater	14	6.2 a
		Graywater	14	4.0 a
	44	Freshwater	11	9.4 a
		Graywater	15	8.6 a
	62	Freshwater	12	17.8 a
		Graywater	13	17.0 a
	97	Freshwater	10	45.8 a
		Graywater	9	45.7 a
Tomato	21	Freshwater	12	20.1 a
		Graywater	12	17.9 a
	44	Freshwater	11	29.6 a
		Graywater	12	25.6 a
	62	Freshwater	12	36.7 a
		Graywater	8	39.8 a
	97	Freshwater	9	71.4 a
		Graywater	7	72.9 a

Figure 5 shows the effects of graywater on vegetable weight, a number of fruits per plant and the fruit sizes in the third year of the experiment. As indicated, no significant changes were observed in weight, fruit counts and fruit sizes of all the vegetables including Bell Pepper, Chile, and Tomato. Although there is a general trend of increasing of plant weight, fruit counts and fruit sizes at all DAPs sampled for different vegetables; no single sampling event showed any significant increases in yield at p=0.05 significance level when irrigated with graywater as compared to freshwater. This suggests that graywater irrigated Bell Pepper, Chile and Tomato does not show any positive or negative response when graywater was used as the irrigation water source.

In general, the vegetable yield that characterized in terms of weight, fruit counts per plant and fruit size in this experiment using graywater as the irrigation water source shows the positive response to graywater irrigation in the first year for Bell Pepper and Chile. On the contrary, the Tomato yield does not respond to different treatments significantly in both first and third year. The Bell Pepper and Chile yield increase significantly under graywater irrigation in the first year, although observed data does not show the same results for the third year. This may be the fact that different freshwater sources were used for the first and third years. That is, the well water with higher concentrated nitrogen was used as freshwater in the first year, while the sand filter effluent water from El Paso City Utilities with lower nitrogen concentration was used as freshwater irrigation in the third year (as indicated in Table 1). The sampling procedure and statistical test results indicating that no yield decrease in terms of fruit weight, fruit counts and fruit size was observed in all vegetable types both in the first and third years at different DAPs, indicating graywater can be a viable alternative, nontraditional irrigation sources option without compromising vegetable growth and yield.

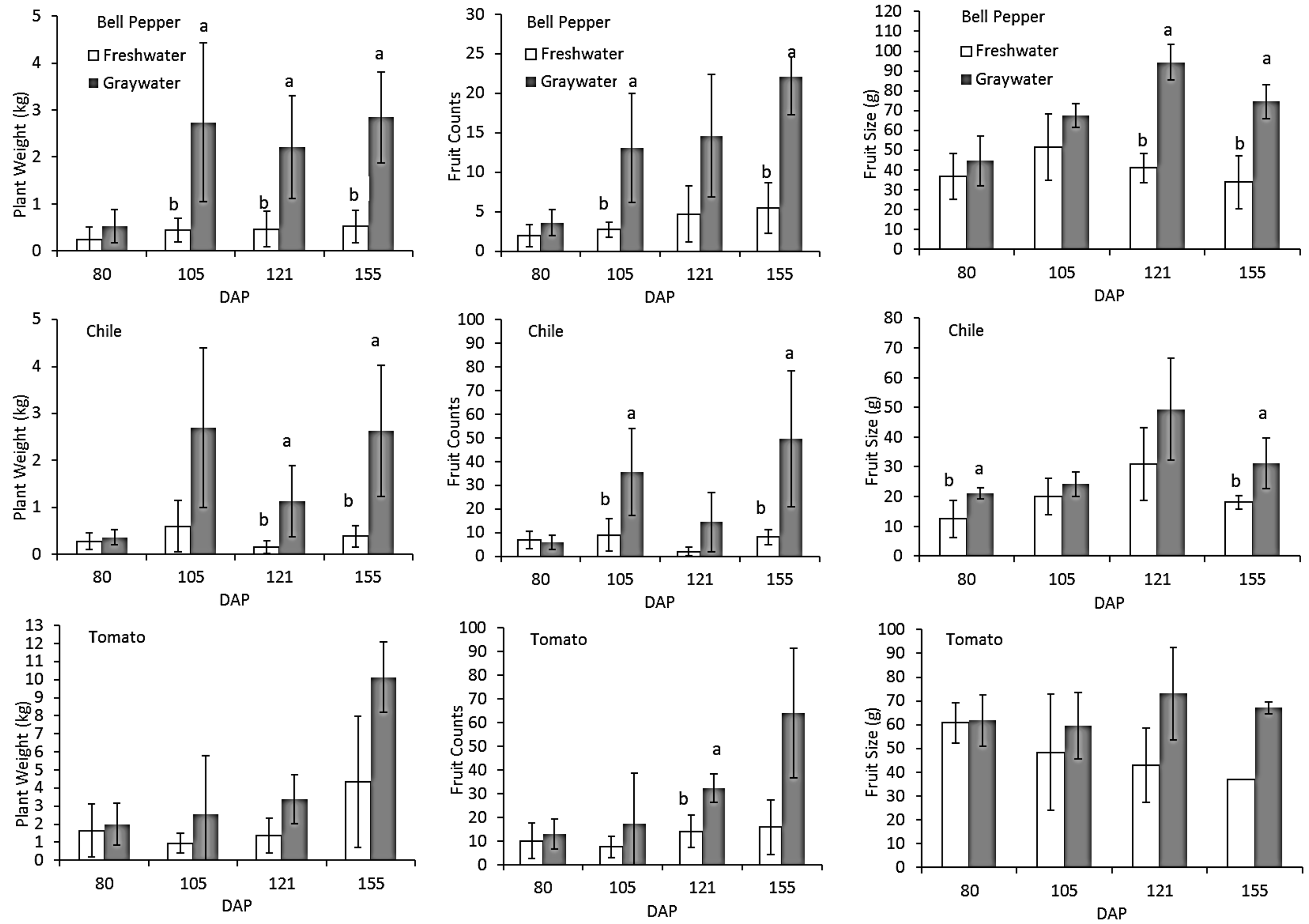

Figure 4. Effects of graywater on vegetable weight, number of fruits per plant and the fruit size during the first year of experiment (marked with a and b are statistically different in means at p=0.05)

The nonsignificant effects of graywater on vegetable plant yield have also been reported in the previous studies. Mzini (2013) conducted comprehensive research on the effects of graywater irrigation on various vegetables and found that graywater irrigation increases the yield of some vegetables such as cabbage and onions, while others such as lettuce, spinach, and carrots do not respond significantly in terms of yield to the graywater irrigation. It is indicated from previous research results and the experiment that the vegetable yield increase under graywater irrigation is largely dependent upon the chemical properties of graywater used and types of vegetable that grown under graywater irrigation. Though long-term impacts of graywater should be further evaluated, the graywater irrigation tends to outperform in terms of plant growth and yield as compared to freshwater irrigation of vegetables. The statistical analysis suggests that the graywater has shown great potential as an alternative water supply for vegetable production in the El Paso region, Texas.

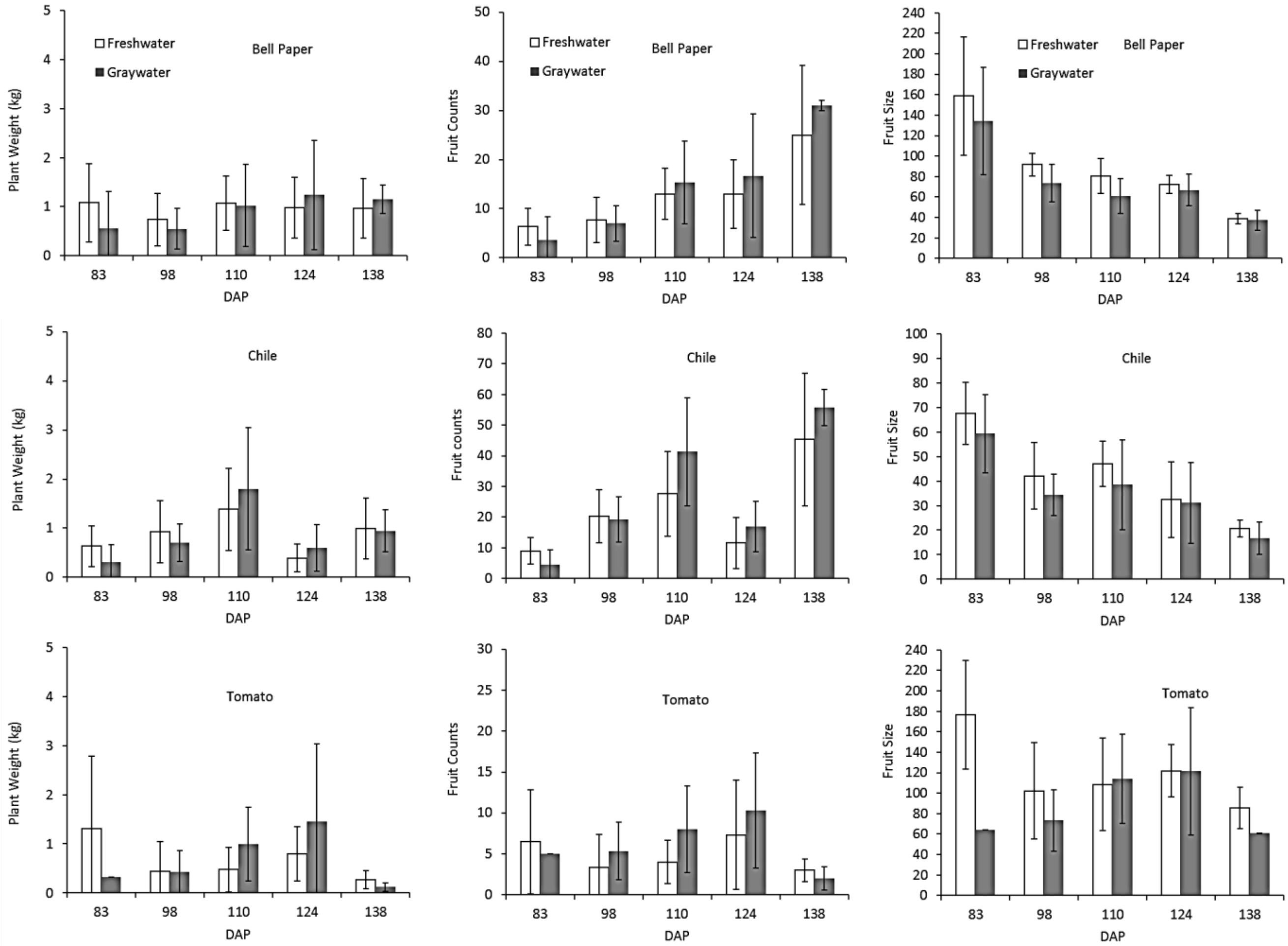

Figure 5. Effects of graywater on vegetable weight, number of fruits per plant and the fruit size in during the third year of experiment (marked with a and b are statistically different in means at p=0.05)

4 Conclusion

Use of alternative sources for irrigation, such as graywater, becomes more attractive as more freshwater resources are diverted for municipal, industrial and domestic uses. However, potential impacts of graywater irrigation with water having elevated salinity on soil salinity and crop yield needs to be evaluated before advocating its use on a large scale. This study presented the results from a field experiment conducted in El Paso, Texas to evaluate the possible effects of graywater irrigation on vegetable crops including Bell Pepper, Chile, and Tomato. Statistical analysis of data was carried out using Duncan's multiple range test based on the sampled vegetable height, weight, number of fruits per plant and the fruit size for Bell Pepper, Chile, and Tomato at different days of planting for the first and third years. The possible effects of graywater irrigation on soil properties including soil pH, salinity and SAR were also evaluated for all years during the experiment.

The experiment results indicated that no evident salt accumulations or changes in salinity and sodicity were observed at the soil surface in the depth of 0-15cm, while soil pH is increased significantly with greywater irrigation. The results showed promising potential for graywater water irrigation for vegetable production in terms of increasing trend in weight, a number of fruits per plant and fruit sizes of vegetables such as Bell pepper and Chile. The graywater irrigation tends to outperform in terms of plant growth and yield as compared to fresh water irrigation of vegetables although no systematic statistical significant test results were concluded on the vegetable yield increase under graywater irrigation from this experiment. Further long-term field experiments are needed to conclude the vegetable yield response to graywater irrigation.

This study presents important findings that further strengthen our understanding regarding the use of graywater for irrigation. The relatively short duration of the study showed that the irrigation of graywater has no negative effects on soil alkalinity, salinity, sodicity and vegetable weight, fruit counts and fruit sizes. The lack of growth data for Bell pepper, Chile, and Tomato because of rodent-eating incident in the second year experiment inhibited us draw a distinct conclusion from this experiment to a certain extent. It is recommended that further studies in the topic be encouraged to verify long-term impacts of graywater water and freshwater irrigation for vegetable production, soil salinity, soil fertility and potential benefit of graywater utilization in crop production in the arid region of the world.

References

1. Al-Jayyousi O R. Greywater Reuse: Towards Sustainable Water Management. Desalination, 2003; 156:181-92.
2. Assadian N, Sheng Z, Gonzales E, Cooper L, Villalobos J, Di Giovanni G. Water Conservation in the Rio Grande Basin through Efficient Reclaimed Water Use, and 2005 Annual Report (04-FG-40-2184) submitted to U.S. Bureau of Reclamation: 16p, 2006.
3. Day A D, Mc Fadyen J A, Tucker T C, Cluff C B. Effects of Municipal waste water on the yield and quality of cotton. J. Environ Qual, 1981; 10:47-49.
4. Emmerson G. Every Drop Is Precious: Greywater as an Alternative Water Source. Brisbane: Research Bulletin No 4/98, Queensland Parliamentary Library, 1998.
5. Finely S, Barrington S, Lyew D. Reuse of domestic greywater for the irrigation of food crops. Water Air Soil Pollut, 2008; 199: 235-245.
6. Gawad G A, Arslan A, Gaihbe A, Kadouri F. The effects of saline irrigation water management and salt tolerant tomato varieties on sustainable production of tomato in Syria (1999–2002). The Arab Centre of the Studies of Arid zones and Dry lands (ACSAD), Division of Soil Studies and Water Uses, Damascus, Syrian Arab Republic. Agricultural Water Management, 2005; 78 (2005) 39–53.
7. Kiziloglu F M, Turan M, Sahin U, Kuslu Y, Dursun A. Effects of untreated and treated wastewater irrigation on some chemical properties of cauliflower (Brassica olerecea L. var. botrytis) and red cabbage (Brassica olerecea L. var. rubra) grown on calcareous soil in Turkey. Agric Water Manag. 2008; 95:716–24
8. Misra R K, Patel J H, Baxi V R. Removal of pollutants by tomato plants during reuse of laundry greywater for irrigation. In: International Conference on Food Security and Environmental Sustainability (FSES)-Kharagpur, India, 2009.
9. Mzini L. The effects of greywater irrigation on vegetable crops and soil. Master's thesis. Department of Environmental and Geographical Sciences, Faculty of Science, University of Cape Town, Rondebosch, 2013.
10. Patel R M, Prasher S O, Goel P K, Madramootoo C A, Broughton R S. Brackish Water Subirrigation for Vegetables. Department of Agricultural and Biosystems Engineering, McGill University, St. Anne de Bellevue, Canada. Irrigation and Drainage, 2003; 52: 121–132
11. Pinto U, Maheshwari B L, Grewal H S. Effects of greywater irrigation on plant growth, water use and soil properties. Resources. Conservation and Recycling, 2010; 54:429–35.
12. Qishlaqi A, Moore F, Forghani G. Impact of untreated wastewater on soils and crops in Shiraz suburban area, SW Iran. Environmental Monitoring and Assessment, 2008; 141 (1-3): 257-273.
13. Radcliffe J. Water Recycling in Australia. Victoria: The Australian Academy of Technological Sciences and Engineering, 2003.
14. Rose J B, Sun G S, Gerba C P. Microbial Quality and Persistence of Enteric Pathogens in Greywater from Various Household Sources. Water Res., 1991; 25:37-42.
15. Rusan M J, Hinnawi S, Rousan L. Long term effect of wastewater irrigation of forage crops on soil and plant quality parameters. Desalination, 2007; 215:143-152.
16. SAS Institute. SAS for Windows 9.1.3., 2006.
17. Sheng Z. An aquifer storage and recovery system with reclaimed wastewater to preserve native groundwater resources in El Paso, Texas,

Journal of Environmental Management, 2005; 75(4): 367-377.

18. Sheng Z, Assadian N, Herrera E, Di Giovanni G, Abdel-Fattah A. Water Conservation in the Rio Grande Basin through Efficient Reclaimed Water Use, 2006 Annual Report (04-FG-40-2184) submitted to U.S. Bureau of Reclamation, 21p, 2007.
19. Texas Commission on Environmental Quality (TCEQ). Texas Administrative Code (TAC) Chapter 210. Subchapter F: Use of Graywater Systems. http://www.tceq.state.tx.us/H. 2005.
20. Toenniessen G H. Review of the world food situation and the role of salt-tolerant plants. In: Staples, R.C. and Toenniessen, G.H. (eds.), Salinity tolerance in plants strategies for crop improvement. Environ. Sci. and Tech. A John Wiley and Sons, Inc. NY, 1984; 399-413.
21. U.S. Salinity Laboratory Staff. Diagnosis and improvement of saline and alkali soils. Agric. Handb. 60. U.S. Gov. Print. Office, Washington, DC. under perennial ryegrass (Lolium perenne [L]). ISRN Ecology, 1954; 1-9.
22. Wiel-Shafran A, Gross A, Ronen Z, Weisbrod N, Adar E. Effects of surfactants originating from reuse of greywater on capillary rise in the soil. Water Science and Technology. IWA Publishing, London, UK: 2005; 52: 10/11, 157-166.
23. Wiel-Shafran A, Ronen Z, Weisbrod N, Adar E. Potential changes in soil properties following irrigation with surfactant-rich greywater. Ecological Engineering, 2006; 26: 4, 348-354.