Impacts of graywater irrigation and soil conditioning with mulch on cotton growth and soil properties

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ABSTRACT

Field experiments were conducted to evaluate the impacts of graywater irrigation with and without soil conditioning with mulching on cotton growth and soil properties in El Paso, Texas, USA. Treatments included in the study were: freshwater irrigation without soil conditioning (control, treatment T0), freshwater irrigation with soil conditioning (treatment T1), graywater irrigation without soil conditioning (treatment T2) and with soil conditioning (treatment T3) with four replications. The pH, sodium absorption ratio (SAR) and electrical conductivity (EC) values of the graywater used in the study were 8.19, 16.0 and 1.54 dS/cm respectively. Results showed that graywater irrigation did not have significant impacts on cotton growth and lint yield. Soil conditioning with mulch increased cotton yield significantly ($p < 0.05$) compared with non-mulching regardless of water types. Graywater irrigation increased soil pH values significantly in the surface depth (0–15 cm), however, it did not have significant effects at greater depths (>15 cm). Significantly higher salinity and sodicity were observed in the upper 30 cm depths in the graywater irrigated mulched soils, while no changes were detected at greater depths (30–45 and 45–60 cm).

Key words | cotton, graywater, salinity, sodicity, soil, soil conditioning with mulch

INTRODUCTION

Rapid urbanization has resulted in a significant increase in freshwater demands for municipal and industrial uses in the southwest USA including El Paso County in Texas, characterized by semiarid conditions. As a result, agricultural users, especially cotton (Gossypium hirsutum L.) growers in the region, are increasingly relying on alternative water sources for irrigation. Use of non-potable alternative water sources such as graywater and reclaimed wastewaters to irrigate suitable agricultural crops can be a beneficial and efficient use of these alternative waters while at the same time it results in reducing pressure on potable supplies (Asano et al. 2007). Graywater comprises bath tub, shower area, hand wash basin, laundry, and kitchen sink water and is usually less polluted than municipal wastewater (also called blackwater), due to the absence of human excretions and toilet paper (Neal 1996; Saeed et al. 2015).

Graywater has been applied widely in landscape irrigation, groundwater recharge and crop irrigation and other areas.

Past research shows that graywater irrigation does not affect crop yield, instead, in some cases, it increases plant growth and yield while maintaining the quality of the crops (Rusan et al. 2007; Finley et al. 2008; Mzini 2013; Han et al. 2015; Mzini & Winter 2015; Lubbe et al. 2016). The impact of graywater irrigation on soil properties is also well documented in the literature. Rusan et al. (2007) reported that the soil pH was not affected due to graywater irrigation although it can accelerate the accumulation of pollutants. Mzini (2013) reported that no significant difference was observed in pH throughout the soil profile of 0 to 90 cm under different treatments of graywater irrigation. Albalawneh et al. (2016) observed a general reduction in salinity of soil (measured by electrical conductivity or EC) when irrigated with
greywater. Wiel-Shafran et al. (2006) reported that greywater irrigated soil pH was significantly lower than that of freshwater irrigated soils probably due to enhanced bacterial activities such as respiration. Some research has shown the opposite results. Pinto et al. (2010) discovered that soil salinity and pH were significantly elevated due to greywater irrigation compared with potable and diluted greywater. Qishlaqi et al. (2008) suggested an increase in soil pH when irrigated with greywater. Faruqui & Al-Jayyousi (2002) reported that greywater irrigation resulted in increased pH, accumulation of salts, and heavy metals but levels remained below the threshold to pose any risks to soil health. Thus, a review of past research suggests no consensus on the effects of greywater irrigation on soil properties.

Conditioning of soil with mulching has become increasingly important for irrigating with alternative waters. Raman et al. (2004) found that sugarcane (Saccharum officinarum L.) trash mulching increased weed control efficiency (91%), weed control index, crop growth, and seed and lint yield of cotton. Vasilakoglou et al. (2006) found that cotton lint yields in mulched cultivated treatments were 28% to 84% greater than that in the corresponding mulch-free treatments. Qin et al. (2015) reported that soil mulching significantly increased yields and yield per unit of water by up to 60%, compared with no-mulching. In contrast to the above results, Virdia & Patel (2000) reported that mulching soil resulted in higher incremental cost and consumptive water use due to more frequent irrigation than no mulch treatment. Conditioning sodic soils with biosolids (organic rich products) may improve soil permeability and tilth by improving soil structure (aggregation) and soil porosity, and therefore could improve soil infiltration and vertical movement of salty irrigation waters.

This paper presents the results of a two-year field experiment conducted in El Paso, Texas, to evaluate the impacts of both greywater and soil conditioning with mulch on cotton production and soil salinity. Specific objectives of the research were to evaluate: (i) the effects of low-cost options such as the application of activated pecan shells and compost application to soils irrigated with greywater on soil permeability; (ii) the effects of greywater irrigation on soil salinity and sodicity at different soil depths; and (iii) cotton growth and yield under greywater irrigation.

**METHODS**

**Experimental design**

This field study was conducted at the Rogelio Sanchez State Jail facility in El Paso, Texas. Study site soil was loamy sand underlain by shallow to deep layers of caliche (calcium carbonate), and the dominant map unit was 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 15 cm. In this experiment, both irrigation and soil conditioning were treatments. Irrigation treatments were prison laundry water (greywater) and well water/tap water (freshwater). Soil treatments were mulching and no mulching with the organic amendment. Activated pecan shells and compost was mixed with top soil to ensure or increase water infiltration and drainage by enhancing soil particle aggregation and porosity. Thus, the four experimental treatments included: the control treatment – freshwater irrigation without soil conditioning \(T_0\), freshwater irrigation with soil conditioning \(T_1\), greywater irrigation without soil conditioning \(T_2\) and greywater irrigation with soil conditioning \(T_3\).

Split-plot experiment design with soil conditioning was used for the main plots with water type as sub-plots and four replications. Each of the four blocks was 12 m long × 10 m wide and was equally (6 m long × 5 m wide) divided for two soil treatments: mulch/organic compost incorporation in the upper 15 cm depth, and no amendment. Each of these sections was further divided into two sub-sections with four rows in each subsection that were 3 m wide (5 m × 3 m) for water treatments. Cotton row spacing of 1 m was used to simulate growers’ practices. Real-time soil moisture was monitored using logger connected Echo\textsuperscript{TM} soil moisture sensors installed at 15 cm, 30 cm, 45 cm, and 60 cm soil depths. Study plots were irrigated twice a week with 946 or 1,892 L/plot (53 m\textsuperscript{2}) from May 12 to September 29. A total of 838 mm of greywater or freshwater was applied to plots, which is comparable to the irrigation water applied by cotton farmers in the region. The rainfall at the site is typically about 200 mm
during the growing season. Annual pan evaporation is approximately 2,500 mm, of which over 1,700 mm is during the growing season. Graywater and freshwaters were also collected from the source and analyzed to characterize salts, nutrients, and metal concentrations. Graywater was slightly alkaline with a pH of 8.19, non-saline with an EC of 1.54 dS m⁻¹, but sodic with a SAR of 16. Sodicity is often observed, but not necessarily problematic when total salt and Ca are in adequate concentrations to counter dispersion caused by sodium.

Baseline water quality and soil properties

Grab samples of graywater and freshwater were collected and analyzed to characterize salts, nutrients, and metal concentrations during the study period as per the methods described in APHA (2005). Graywater was slightly alkaline with a pH of 8.19, non-saline with an EC of 1.54 dS m⁻¹, but sodic with a SAR of 16. Sodicity is often observed, but not necessarily problematic when total salt and Ca are in adequate concentrations to counter dispersion caused by sodium. Soil samples from the study sites were collected before the study and after each irrigation season. Soil samples were processed and analyzed for texture, pH, EC, major cations (Ca, Mg, Na), and anions (Cl, NO₃, PO₄ and SO₄) as per the methods described by Sparks (1996). The sodium adsorption ratio (SAR) of the soil was determined using cation concentrations and the empirical formula. The chemical characteristics of soil and the organic mulching are shown in Table 1. The soil was moderately alkaline but not saline (EC < 4 dS m⁻¹) based on column test results. Total N, NO₃-N, and NH₄-N were at low concentrations. Concentrations of plant-available N (NO₃-N and NH₄-N) translated to about 45 kg/ha. Therefore, the soil was considered N deficient. Soil sodicity was very low, and average SAR was less than 1. Conversely, the compost used as a soil conditioner had a near-neutral pH and was rich in nitrogen and phosphorus.

Cotton establishment and harvesting

Pima cotton, Delta-Pine roundup ready (DP 393) cultivar, is popular in west Texas. This cultivar was used in our study. Cotton seeds were planted manually when the surface soil temperature reached 21 °C. In each row cotton seeds were planted about 10 cm apart at an approximate depth of 2.5 cm. Four seeds of cotton were planted in each hole to increase the chance of survival of at least one plant per hole. Initially, plants were irrigated daily to increase the chance of survival. Once plants were established, irrigation frequency was reduced to twice per week. The crest of the base was removed to help cotton siblings to take their stands. Plant heights were measured on 32, 63, 84 and 132 d after planting (DAPs), respectively. Both boll weevil and pinky bollworm traps were set up and maintained under the supervision of Texas Boll Weevil Eradication Program West Texas Office staff. Seed cotton and lint yields were determined from one harvest at the end of the growing season. Cotton was collected from one sample from each subsection. Each sample contained five cotton plants.

Statistical analysis

A split plot design with two soil treatments (mulching or no mulching) as main plots, two types of irrigation water (graywater and freshwater) as sub-plots and soil depths as sub-sub plots were used with four replications. The significance of treatment effects was analyzed using Duncan’s multiple range tests (Duncan 1955) at the 0.05 level of probability using Statistical Analysis Software (SAS 2006).

<table>
<thead>
<tr>
<th>Chemical parameter</th>
<th>Loamy sand</th>
<th>Organic compost*</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>8.78</td>
<td>7.79</td>
</tr>
<tr>
<td>EC (dS m⁻¹)</td>
<td>0.195</td>
<td>9.10</td>
</tr>
<tr>
<td>Available Ca (mg kg⁻¹)</td>
<td>22.9</td>
<td>67.9</td>
</tr>
<tr>
<td>Available Mg (mg kg⁻¹)</td>
<td>3.92</td>
<td>40.8</td>
</tr>
<tr>
<td>Available Na (mg kg⁻¹)</td>
<td>4.86</td>
<td>710</td>
</tr>
<tr>
<td>SAR</td>
<td>0.247</td>
<td>16.7</td>
</tr>
<tr>
<td>TKN (mg kg⁻¹)</td>
<td>135</td>
<td>8,992</td>
</tr>
<tr>
<td>NH₄-N (mg kg⁻¹)</td>
<td>3.20</td>
<td>&lt;MDL⁹⁶</td>
</tr>
<tr>
<td>NO₃-N (mg kg⁻¹)</td>
<td>6.93</td>
<td>&lt;MDL⁹⁶</td>
</tr>
<tr>
<td>Olsen P (mg kg⁻¹)</td>
<td>4.61</td>
<td>394</td>
</tr>
</tbody>
</table>

*Omni Planting Compost.  
⁹⁶MDL, method detection limit.
RESULTS AND DISCUSSION

Cotton growth and lint yield

Cotton height was significantly affected by different treatments (Figure 1). Cotton heights at the end of growing seasons were significantly higher under freshwater irrigation with soil conditioning compared with freshwater irrigation without conditioning in both growth years. No significant differences were observed in cotton heights between freshwater irrigation with soil conditioning and graywater irrigation with soil conditioning during both years. Thus, it may be concluded that the soil conditioning with mulch had significant impacts on cotton height growth only when the cotton was irrigated with freshwater. These results are comparable to the findings of the past studies. Pinto et al. (2010) reported no significant difference in silverbeet growth over 60 d when irrigated with freshwater or graywater. Travis et al. (2010) also did not observe significant differences in lettuce heights between gray and freshwater irrigations. The first-year data analysis of our study suggests that a small difference may be observed in cotton growth when irrigated with graywater without soil mulching. However, additional years of study will be needed to reach a systematic conclusion.

Moreover, graywater quality varies immensely, and the use of various wastewaters for irrigation may have different effects on plant growth. Nutrients contained in wastewater may increase plant growth, but the long-term effects are largely unknown (Kiziloglu et al. 2008). Plant growth in response to graywater irrigation appears to be dependent on the type of crop and nutrient content of the irrigation water.

The effects of the four treatments on cotton lint yield in both years are also shown in Figure 1. Both years’ data indicated that graywater irrigation did not significantly affect the cotton yield. Non-significant effects of graywater on plant yield have also been reported in previous studies. Finley et al. (2008) found no significant difference in lettuce and carrot growth between gray and tap water irrigations.

![Figure 1](https://iwaponline.com/ws/article-pdf/19/4/1080/593619/ws019041080.pdf)

**Figure 1** Effects of different treatments (T0=freshwater without mulching; T1=freshwater with mulching; T2=graywater without mulching; and T3=graywater with mulching) on cotton growth and lint yield during the study duration.
irrigation. 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 the effects on yields of other crops such as lettuce, spinach, and carrots were not significant.

No significant impacts of mulching treatments on cotton lint yield were observed in the first year for both irrigation waters. However, the second-year cotton lint yield was significantly higher under soil conditioning with mulch than with no mulching regardless of irrigation treatments. Graywater irrigation with soil conditioning produced approximately 65% more lint than that without mulching. With soil conditioning, freshwater produced cotton/lint approximately 1.5 times higher than without soil conditioning. This combined impact of soil conditioning with freshwater is also reflected in the growth rate. These results imply that freshwater could be used more efficiently with appropriate soil conditioning such as mulching than with no mulching.

### Soil pH

Effects of different treatments on soil pH at different soil depths (0–15 cm, 15–30 cm, 30–45 cm, and 45–60 cm) are summarized in Figure 2. No significant changes in pH values were observed at greater soil depths of 15–30 cm, 30–45 cm and 45–60 cm under graywater irrigation and soil mulching. This is because soil conditioning with mulch applied only in the top soil zone (0–15 cm soil depth). In the upper 15 cm soil depth where the mulch was applied, treatment effects were significant. As evident from Figure 2, the maximum pH value was observed in T2 probably due to the higher pH of graywater than freshwater. In addition, the organic compost that was used for soil conditioning had lower pH than the baseline pH of the study site soil. In general, results indicated that the soil mulching lowered soil pH at 0–15 cm under graywater irrigation.

Previous study results do not report a consistent trend for the effects of graywater on soil pH. Some studies have reported an increase in soil pH values (Qishlaqi et al.)
2008; Pinto et al. 2010), some research has found no significant impacts on soil pH values (e.g., Mzini 2013), while others report the lowering of pH under graywater irrigation (Wiel-Shafran et al. 2006). Our results showed that the graywater irrigation increased soil pH significantly in the top soil (0–15 cm), while no significant effects on the soil pH values were observed at greater depths (>15 cm). The soil conditioning with organic mulching lowered soil pH values in the upper 15 cm. Our results suggest that the long-term application of graywater could lead to an increased soil root-zone alkalinity, however, soil pH increase can be mitigated by periodic leaching with freshwater and organic mulching of surface soils (0–15 cm).

Soil salinity and SAR

Different treatments had significant effects on soil salinity at the different soil depths of 0–15 cm, 15–30 cm, 30–45 cm, and 45–60 cm as shown in Figure 3. Salinity at 0–30 cm depth in mulched soils irrigated with graywater was significantly greater than graywater irrigated mulched soils at 30–60 cm depths. No significant soil salinity changes were observed at soil depths of 30–45 cm and 45–60 cm. In addition, the soil salinity at the soil depth of 0–30 cm was greater than that at the 30–60 cm depth under all treatments. Results indicated higher salinity levels for the upper 30 cm in the graywater irrigated mulched soils. However, none of the soils irrigated either with graywater or freshwater could be considered as saline (EC > 4 dS m⁻¹).

Salt accumulation in the upper 30 cm under graywater irrigation with soil mulching could be due to the higher salinity of organic compost than the initial salinity of the study soils. Salinity compost coupled with that of graywater could have resulted in higher salt concentration in the upper 30 cm of this treatment. However, this did not result in excessive leaching of salts to greater depths because mulching increased water infiltration and drainage by enhancing soil particle aggregation and porosity.

Figure 3 | Effects of different treatments (T₀—freshwater without mulching; T₁—freshwater with mulching; T₂—graywater without mulching; and T₃—graywater with mulching) on soil salinity (electrical conductivity, EC) under different soil depths.
result showed that the impacts of soil conditioning on soil salinity varied depending on the interaction of mulch and irrigation water.

Soil sodicity changes followed a similar trend as salinity. For example, the graywater irrigated mulched soils showed significantly greater ($p < 0.05$) sodicity than other treatments at soil depths of 0–30 cm, while no significant changes in SAR values were observed among treatments at the soil depth of 30–60 cm ($p > 0.05$). SAR values at 0–15 cm depth in mulched soils irrigated with graywater were significantly greater than graywater irrigated mulched soils at other depths. The main reason for the highest SAR values at the soil depth of 0–30 cm under graywater irrigation with soil mulching is that the SAR values of both graywater and organic composite mulching are higher than freshwater and original soils respectively (organic composite SAR = 16.7, loamy soil SAR = 0.247, as shown in Table 1). The combination of these two factors resulted in significantly higher SAR values in the cotton cultivated soil at a depth of 0–30 cm. Identical to soil salinity, higher sodicity was observed in the top soil depth of 0–30 cm in the graywater irrigated mulched soils. This trend shows that the dominant salts in the study site are probably sodium salts. Application of gypsum with an organic amendment may remediate sodium-affected soils, and in combination with wastewater, irrigation may improve soil conditions even more efficiently than an organic amendment alone because of the greater abundance and higher solubility of calcium.

Overall, the results of this study indicated an accumulation of salts under T3 and are comparable to the previous research results that reported an increase in soil salinity under graywater irrigation (Pinto et al. 2010). 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 the monsoon season at the experimental site may have helped to flush out salts from the top soil and increased cotton growth as well as lint yield.

**CONCLUSIONS**

Use of alternative sources, such as graywater for irrigation, becomes more attractive as more freshwater resources are diverted for municipal, industrial, and environmental uses. Results of our study show that freshwater irrigation with soil conditioning increased cotton height. Soil conditioning effects were greater for cotton irrigated with freshwater than irrigated with graywater. This indicated that soil conditioning can alleviate impacts of salinity on cotton growth. Study results showed that graywater irrigation does not significantly affect cotton lint yield. Instead, the soil conditioning with mulch had significant impacts on cotton yield and mulching increased lint yield compared with no mulching regardless of irrigation water quality. It indicated that graywater and freshwater could be used more efficiently with mulching. Our results showed that the graywater irrigation increased soil pH values significantly in the upper 15 cm, while there were no significant effects at greater depths (>15 cm). Soil conditioning with organic mulching lowered soil pH values in the upper 15 cm depth. The results of the present study suggest that the long-term application of graywater could lead to increased soil alkalinity, but this could be managed with periodic leaching of salts by applying freshwater and soil conditioning with organic mulching. Salinity and sodicity were greater in soils mulched with organic compost because of the greater salinity of the compost. Thus, selection of aged compost with less salinity is important.

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