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Effect of Treated Domestic Wastewater on Physical and Chemical Characteristics of Soils

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Abstract: The study was carried out to determine the effect of treated domestic wastewater (TDW) on physical, chemical and microbial properties of three soils. There was no significant change in the sand, silt and clay fractions after 458 days of TDW irrigation. The parameters included soil pH, which remained within moderately alkaline region after 458 days of TDW irrigation. The SAR of A and B soils changed from 3.27-2.95 and 3.67-2.15, respectively after 200 days of irrigation. But, the decrease in SAR was less in the same soil when irrigated with TDW continuously for 458 days compared to 200 days due to salt leaching to lower soil depths. The concentration of cations (Na^+, K^+, Ca^{2+}, Mg^{2+}) showed significant ($p<0.001$, $p<0.032$) increase after 200 days followed by a significant ($p<0.001$, $p<0.008$) decrease after 458 days of TDW irrigation. The concentrations of Na^+ in A and B soils decreased with the soil depth except soil C which showed the highest concentration of K as 13.9 meq L^{-1} than the control sample as 3.2 meq L^{-1} after 200 days of irrigation and at 150 cm soil depth. The K^+ concentration increased from 0.2 to 0.5 meq L^{-1} and 0.2-0.8 meq L^{-1} in A and B soils, respectively. However, at 458 days of irrigation, the K^+ concentration dropped below, 0.2 meq L^{-1} in both samples. The electrical conductivity (EC), sodium absorption ratios (SAR), cations (Na+, K^+, Ca^{2+}, Mg^{2+}) and anions (CO_3^{2-}, HCO_3^-, Cl^-, SO_4^{2-}) showed similar patterns. But the values of these cations/anions increased after 200 days of irrigation which again dropped below the initial values of soils. The average number of bacteria in soil A, B and C after 200 days and 458 days of TDW irrigation were 99 and 393 cells, 149 and 333 cells and 56 and 559 cells, respectively. In addition to the above, the microbial analysis indicated that *E. coli* was absent in all the soils irrigated with TDW. The research findings suggest that although the TDW irrigation did not mainly affect the physical and chemical properties of soil under investigation, but is likely to contaminate the groundwater on long term basis in Riyadh region.

Key words: Irrigation, treated domestic wastewater, soil texture, soil physical, chemical, cations, anions, microbes

INTRODUCTION

Saudi Arabia is an arid country with limited and non-renewable water resources. The main sources of water supply are desalinated plants and the groundwater aquifer in Wadi Hanifa. According to recent statistics, the domestic waste effluent water increased from 420×10^3 m^3 day^{-1} in 1993 to 538.5×10^3 m^3 day^{-1} in Riyadh Municipality in 2007 (GDWRR, 2008). Out of this, 396.3×10^3 m^3 day^{-1} (94.4%) of the domestic wastewater was treated in 1993 which increased to 536.3×10^3 m^3 day^{-1} (99.6%) in 2007 (GDWRR, 2008). Most of the treated wastewater is used for irrigating agricultural fields in the suburbs areas and landscape irrigation in Riyadh City as both treated and untreated wastewater are considered good sources of nutrients for plants (Costanzo *et al*., 2001). In addition, TDW may add certain types of beneficial microorganisms to support soil metabolic activities. On the other hand, TDW may pose both environmental and health risks by contaminating soil and underground water (Meli *et al*., 2002). It is, therefore, important to investigate the impact of TDW on soil characteristics and its consequences on underground water (Pereira *et al*., 2002). As Riyadh is part of the Arabian Peninsula desert. Its soils are characterised by high rates of infiltration (Kass *et al*., 2005; Rattan *et al*., 2005; Candela *et al*., 2007).

Treated and untreated domestic wastewaters make the soil system more complex because these contain both the organic and inorganic compounds which influence the cation exchange capacity or the total number of negatively charged binding sites on the soil colloids (Parker, 1997). Parker (1997) stated that the pH of the soil increased with increasing wastewater inputs, while the carbon nitrogen ratio decreased. Also, high concentration of cations such as Na^+, K^+, Mg^{2+} and Ca^{2+} in the wastewater can increase the base saturation status of soil. Other factors that may also influence ion exchange capacity are the presence of calcium in high concentrations, organic materials and soil texture. Calcium, for example is preferentially exchanged at higher concentrations in comparison with iron, manganese and phosphorus (Faz Cano *et al*., 2008; Heidarpour *et al*., 2007; Yadav *et al*., 2002). The cations exchange-capacity depends mainly on the texture and the organic matter content of the soil (Peinemann *et al*., 2000; Stewart and Hossner, 2001). The purpose of this study was to determine the impact of prolonged irrigation with treated domestic wastewater on the physical and chemical characteristics of different soils.

MATERIALS AND METHODS

The study was carried out at the University Research Station, Riyadh during 2006-07 season. The simulation model used in this study is presented in Fig. 1. Each column was packed with three different types of soils [sandy loam, Torrifluvents (A), loamy sand, Torripsamments (B) and Sandy, Aridisol (C)] collected from Agricultural Research Station Derab, Riyadh. The experimental soil was added in successive layers, each 20 cm height to each column over a bed of stones with a height of 40 cm. The total amount of soil in each column was 526 kg of 3.10 m height. The bulk densities of these soil were 1.55, 1.60 and 1.65 for A, B and C soils, respectively. The soils were compacted accordingly to make uniform columns for experiment and replicated thrice. The treated domestic wastewater (TDW) was obtained from the King Saud University wastewater station and was added slowly approximately over 2 days, or until it started discharging from the drainage outlet (diameter = 15 cm; Fig. 1). Then the TDW was added in 4 periods; 19.15 L on 25 April, 319.10 L on 6th June; 671.16 L on 26th July and 233.98 L on 8th August 2006. The mean chemical composition of treated domestic wastewater is shown in Table 1. The total quantity of applied treated domestic wastewater were calculated according to the rate of water evaporation per day in Riyadh District using the following equation:

$$\text{Amount of added water day}^{-1} = \text{Average of evaporated water day}^{-1} \times 1.5$$

Table 1: Mean chemical composition of treated domestic wastewater (TDW)[1]

Parameters	Values	Standard deviation
pH	7.90	0.66
EC	876 (dS cm^{-1})	57.00
$CaCO_3$	876 me L^{-1}	9.64
Cations (me LG[1])		
Na^+	81	11.14
Ca^{2+}	79	6.93
Mg^{2+}	22	4.58
SAR	11.40	
Anions (me LG[1])		
Cl^-	200	38.74
HCO_3^{2-}	66	7.00
SO_4^{2-}	146	12.29

[1]Values in table are means of three replicates

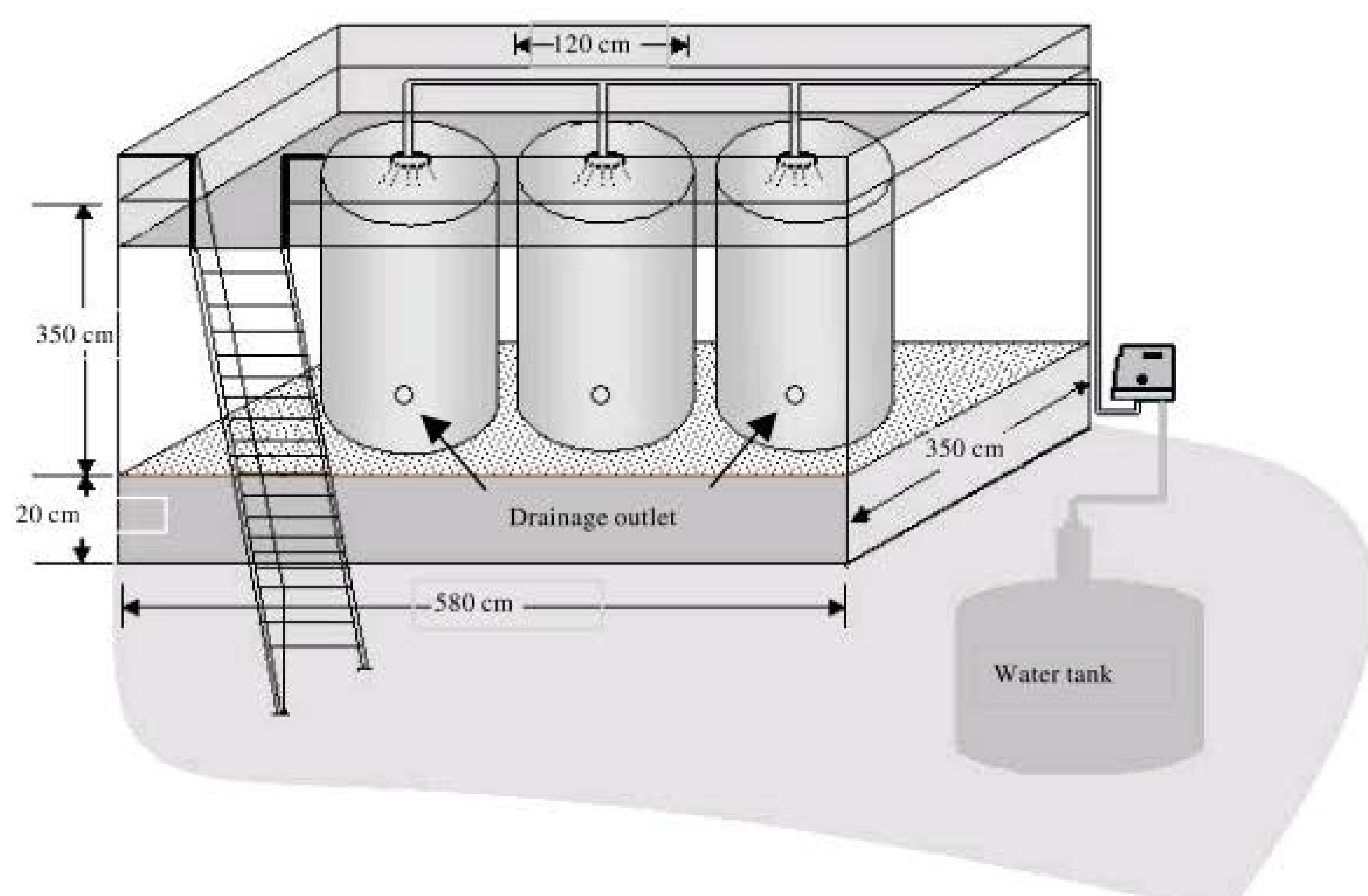

Fig. 1: Simulation model used in the study to determine the effect of treated domestic wastewater on soil properties

Soil samples were collected after 0, 200 and 458 days interval of irrigation with TDW using the screw auger. About 200 g of each soil sample was collected from 50, 100 and 150 cm depth from the soil surface and replicated thrice. The soil samples were analysed for particle sizes (sand, silt and clay contents) using the method of Richard (1954). The soil texture was determined using the soil texture triangle. The percentages of sand, silt and clay were also used to determine the hydraulic properties of soil samples using the Hydraulic Properties Calculator.

The calcium carbonate contents of soil samples were analysed using Calciometer (Loeppert and Suarez, 1996), soil pH was determined using a pH meter on saturation paste, while the electrical conductivity (EC) was measured using an EC meter on saturation paste extract (Rhoades, 1996; Thomas, 1996). The cations (Na^+, K^+, Ca^{2+}, Mg^{2+}) and anions (CO_3^{2-}, HCO_3^-, Cl^-, SO_4^{2-}) were analysed according to standard methods (Richards, 1954; Rainwater and Thatcher, 1979). Sodium absorption ratios (SAR) were calculated according to Richards (1954) using the following equation:

$$SAR = \frac{Na}{\sqrt{(Ca + Mg)/2}}$$

Statistical analysis: Soil hydraulic and physico-chemical properties were analysed by mean and standard deviation. Statistical differences of different attributes were estimated using t-test to evaluate the effect of irrigation intervals among 0-200, 0-458 and 200-458 days.

RESULTS AND DISCUSSION

Hydraulic properties of soil: The results indicated that the three different soils are mainly dominant by sand contents. The sand contents were 80.0, 88.4 and 90.9% in three different soils, respectively before irrigation. (Table 2). The clay was 14.1, 9.1 and 9.1% in the three soils while the rest represented the percentage of silt fraction in the three A, B and C soils, respectively. The application of TDW reduced the sand contents around 5% in soil B and 3% in soils A and C when irrigated for 200 days and 458 days as compared to control treatment (0-day of irrigation) due to the addition of suspended solids. The clay fraction also showed slight increases around 2% and the silt fraction increased slightly due to TDW irrigation from 5-9.33, 5-6.33 and 0-3.67% in A, B and C soils, respectively. In addition, particle size analysis did not show any significant differences in the sand, clay and silt contents at 50, 100 and 150 cm depth from soil surface. Overall, the slight changes in sand, clay and silt fractions of soils by TDW irrigation did not affect the soil texture of the three soils according to the standard soil classification scheme of USDA (1998) (Table 2). This small variation in the different soil fractions could be due to heavy load of suspended solids in the domestic waste water.

Table 2: The effect of TDW on the texture of soils (A, B and C)[1]

	Irrigation duration (day)[2]		
Soil sample	0	200	458
A	Sandy loam	Sandy loam	Sandy loam
B	Loamy sand	Loamy sand	Loamy sand
C	Sandy	Loamy sand	Sandy

[1]Values represent means of the three replicates. [2]Soil textures were determined using online equation

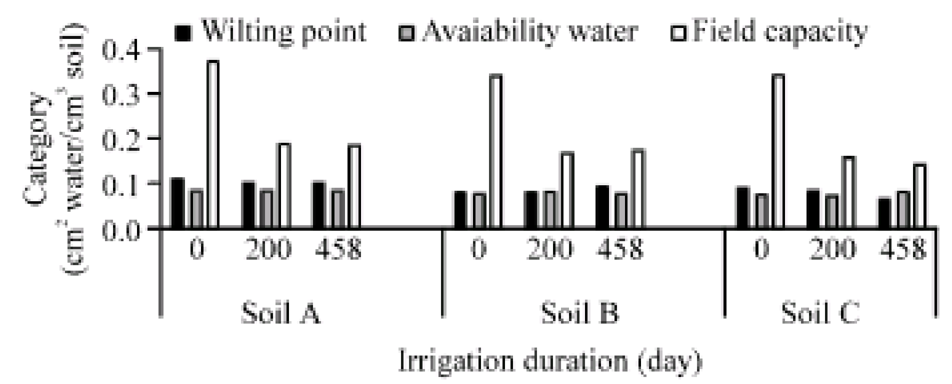

Fig. 2: Effect of irrigation duration on the mean hydraulic properties of soils

The results indicated that wilting points increased significantly in soil B (probability less than 1%, $p<0.01$) by 1.17 fold receiving TDW irrigation for 458 days. Most of the other hydraulic properties of all the soils did not change significantly throughout irrigation with TDW (Fig. 2). The values of wilting point, field capacity and available water of three soils at different depths showed differences ranging between 0.051 and 2.26% and cannot be attributed to TDW irrigation. Because this variation is due to the difference in texture of different soils. The results agree with those of Van Genuchten (1980), Mualem (1986), Van Genuchten *et al.* (1992), Beyazgül *et al.* (2000), Cristine *et al.* (2000, 2003) and Jiang *et al.* (2007) who stated that the relationship between soil and water is essential for determining the physical properties of the soil system such as wilting point, field capacity and quantity of available water including soil hydraulic properties, water holding capacity and the availability of nutrients for plants and subsequently crop production. Because the high level of suspended solids in domestic wastewater can influence the macro-pores of soil after irrigation.

Effect of TDW on cations profile of soils: The chemical analysis of soils after 0, 200 and 458 days of TDW irrigation did not show any significant affect on different soils parameters and the difference among various soil attributes was not significant (i.e., 0 and 200 days, 0 and 458 days and 200 and 458 days). Figure 3a shows the pH profiles of three soils at 50, 100 and 150 cm depth from soil

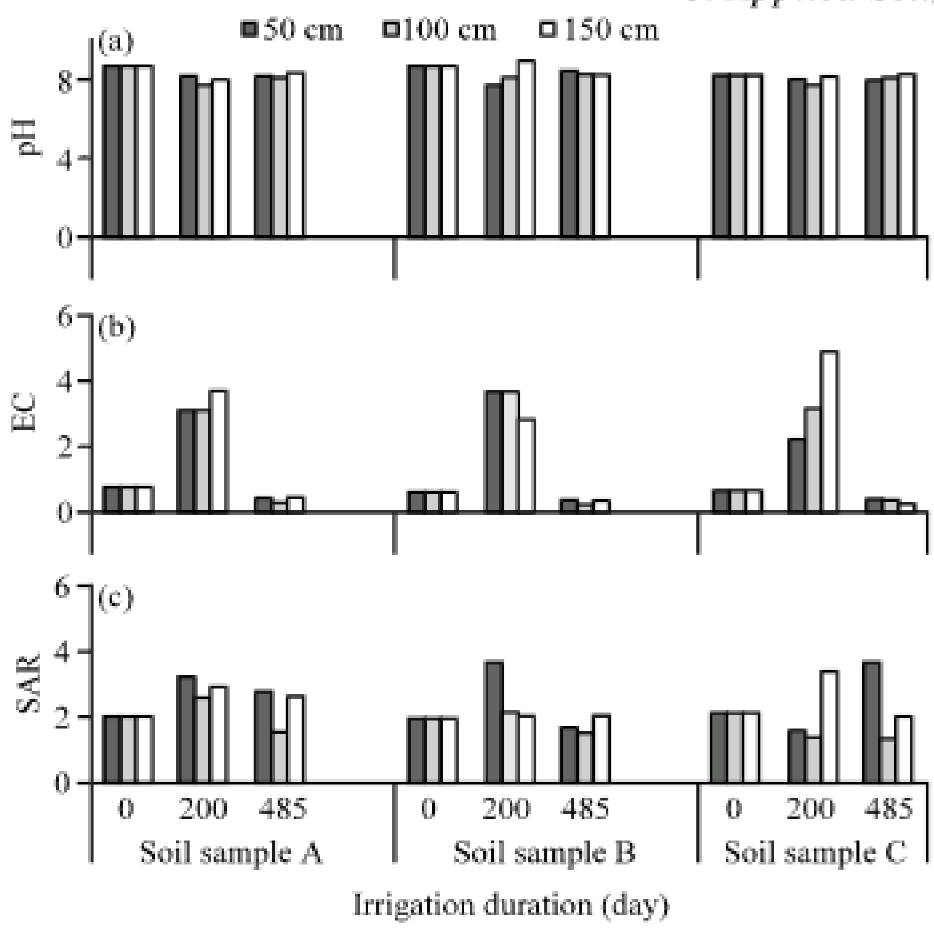

Fig. 3: Effect of irrigation duration on pH, EC and SAR profiles of three soils (A, B and C) by soil depth

surface after 0, 200 days and 458 days of TDW irrigation. According to the USDA (1998) soil classification scheme, the A, B and C soils are characterised as moderate (pH = 7.9-8.4), strong (pH = 8.5-9) and slightly (pH = 7.4-7.8) alkaline in nature, respectively. The initial pH of A, B and C soils was 8.7, 8.4 and 8.3, respectively. After 200 days and 458 days of irrigation, the pH range of A, B and C soils was 7.8-8.4, 7.9-9 and 7.8-8.3, respectively. These results indicate that the pH of soils (A, B and C) remained in the alkaline region after 458 days of irrigation. The minor change in pH of some soil samples could be attributed to the moderate alkalinity of the TDW (pH = 7.9; Table 2). None of the soil samples appears to be in the optimum pH range for plant growth. Because, USDA (1998) reported that the most favourable pH range for optimum plant is between 6-7 which is slightly acidic to neutral and plant nutrient availability is maximum.

Irrigation with TDW showed significant differences of irrigation durations on soil parameters ($p<0.01$, $p<0.05$). EC of soils increased significantly by 3.3-4.6 folds than the control treatment but again decreased below the salinity levels of control treatment after 458 days of irrigation (Fig. 3b). However, the EC values of soils were different at different soil depths especially in soil C where the soil salinity increased with increasing depth of soil. This could be attributed to high amount of irrigation water that caused excessive salt leaching from top to lower soil depths. Many investigators have considered EC as the main parameter for water salinity as it is related to soil properties, including soil moisture, particle sizes and its organic composition (Sheets and Hendrickx, 1995; Inman *et al*., 2002; King *et al*., 2003; Kachanoski *et al*., 1990; Banton *et al*., 1997). Overall, the EC and SAR are used for assessing the heterogeneous nature of spatial distributions of soil salinity (Pozdnyakova and Zhang, 1999; Cristine *et al*., 2000).

The SAR of A, B and C soils increased significantly in most cases by 1.5 folds ($p<0.001$, $p<0.006$) and 1.9 folds ($p<0.001$, $p<0.011$), respectively when irrigated with TDW for 200 days (Fig. 3c). On the other hand, continuous irrigation with TDW for 458 days decreased SAR slightly than the control treatment. The SAR of soil C decreased significantly ($p<0.001$, $p<0.011$) with increasing irrigation duration. In addition, the SAR of soils did not show significant changes with respect to soil depth for all irrigation periods. For example, after 200 days of irrigation, the SAR of A and B soils changed from 3.27-2.95 and from 3.67-2.15, respectively. However, the decrease in SAR was less in the same soil when irrigated continuously for 458 days compared to 200 days of TDW irrigation due to salt leaching to lower soil depths.

The concentration of cations (Na^+, K^+, Ca^{2+}, Mg^{2+}) showed significant ($p<0.001$, $p<0.032$) increase after 200 days followed by a significant ($p<0.001$, $p<0.008$) decrease after 458 days of TDW irrigation (Fig. 4a). The concentrations of Na^+ in A and B soils decreased with the soil depth except soil C which showed the highest concentration of K as 13.9 meq L^{-1} than the control sample as 3.2 meq L^{-1} after 200 days of irrigation and at 150 cm soil depth (Fig. 4b). The K^+ concentration increased from 0.2 to 0.5 meq L^{-1} and 0.2-0.8 meq L^{-1} in A and B soils, respectively. However, at 458 days of irrigation, the K^+ concentration dropped below, 0.2 meq L^{-1} in both samples (Fig. 4c). According to USDA (1998), a soil with a pH 7.8 or more are abundant in Ca^{2+} and Mg^{2+} (Fig. 4d). Thus, the high pH (i.e., 7.8 to 9) of soil samples A, B and C may explain the high concentrations of Ca^{2+} and Mg^{2+} in soil samples during the course of irrigation with TDW. The nature of various chemical interactions in soils is associated with the charges of the cation exchange capacity, which has a negative correlation with irrigation (Parker, 1997).

The initial concentration of calcium carbonate ($CaCO_3$) of experimental soils A, B and C was 13.1 meq L^{-1}, 10.1 meq L^{-1} and 10 meq L^{-1}, respectively. There was no significant increase in $CaCO_3$ concentration [soil A (0.03-3.22 meq L^{-1}), B (0.45-3.14 meq L^{-1}) and C (1.31-2.1 meq L^{-1})] after 200 days of TDW irrigation than the control treatment (Fig. 5a). However, these values decreased by 0.06 to 2.73 meq L^{-1} after 458 days of TDW irrigation. This slight change in the $CaCO_3$ concentration may be attributed to the moderate alkalinity (pH = 7.9) of TDW thus increasing precipitation of $CaCO_3$ in soil

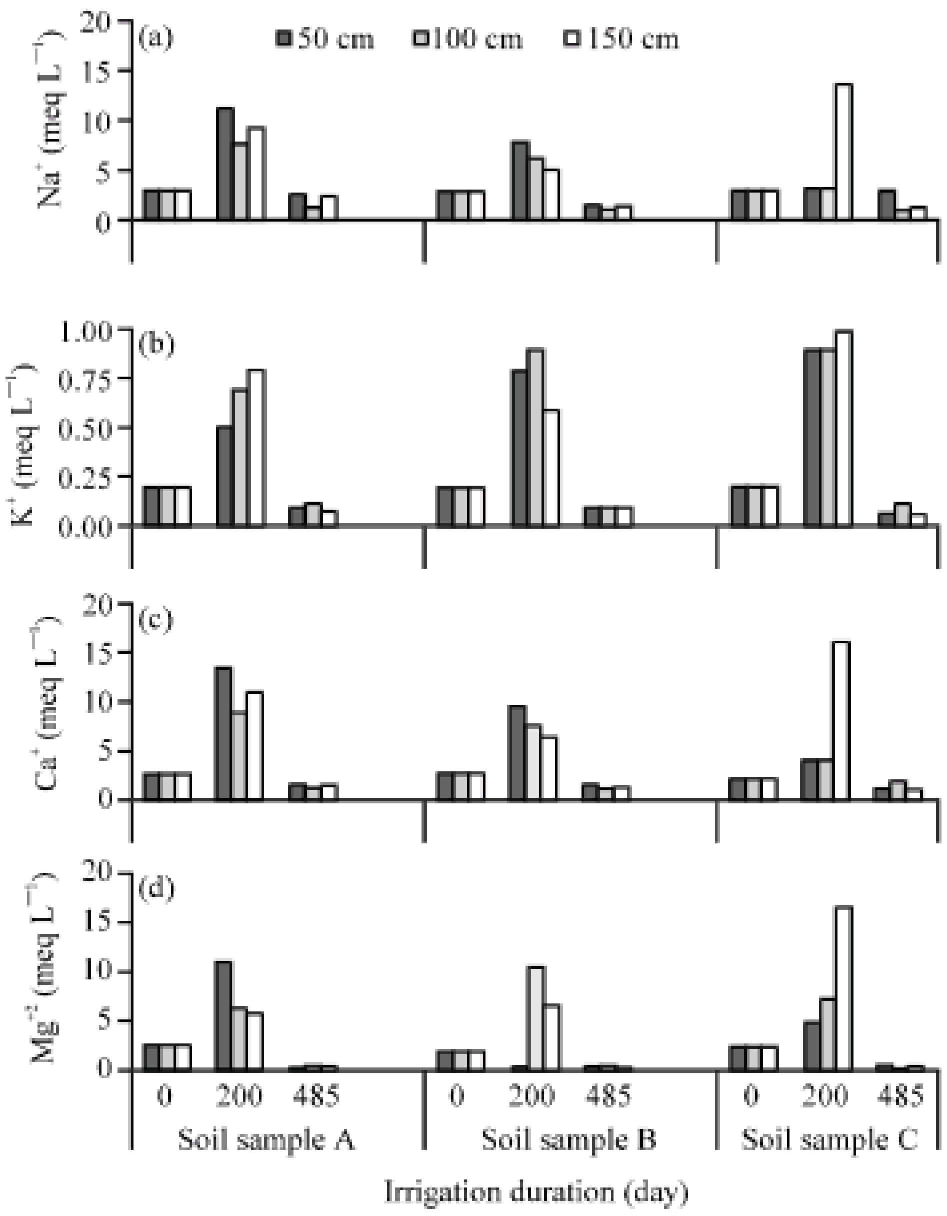

Fig. 4: Effect of irrigation duration on cations profiles of three soils (A, B and C) by soil depth

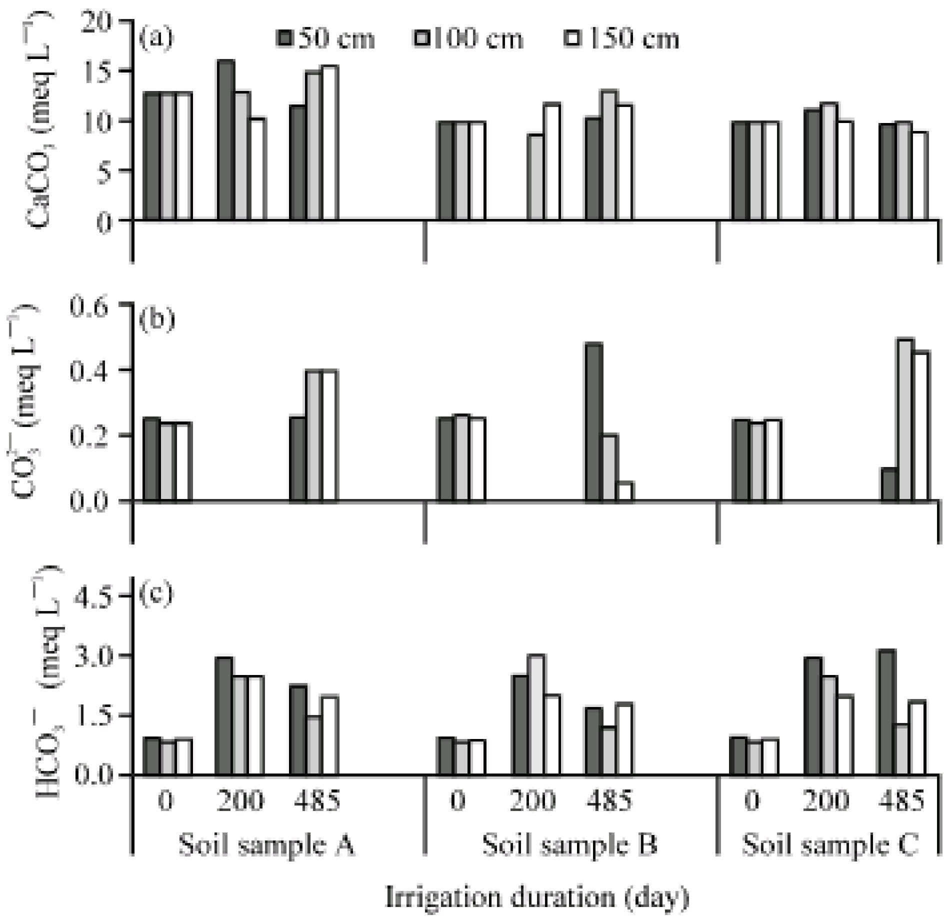

Fig. 5: Effect of irrigation duration on $CaCO_3$, CO_3^{2-} and HCO_3^- profiles of three soils (A, B and C) by soil depth

solution. The results are similar to those of Bailey *et al.* (1998) who observed that high pH of irrigation water can reduce the availability of micronutrients to plants, because $CaCO_3$, Mg $(HCO_3)_2$ and $NaHCO_3$ in irrigation water are the major contributors to alkalinity of the soils and change the solubility of many nutrient elements in soil solution around plant roots.

Effect of TDW on anions profile of soils: Results indicated that mean concentration of CO_3^{2-} decreased significantly ($p<0.001$, $p<0.011$) in soils after at 200 days of TDW irrigation then increased significantly ($p<0.001$-$p<0.033$) after 458 days of irrigation. The concentration of CO_3^{2-} in soils approximately increased 2 times after 458 days of irrigation (Fig. 5b) than the initial CO_3^{2-} concentration which ranged from 0.23-0.26 meq L^{-1}. After 458 days irrigation, the CO_3^{2-} content were 0.05-0.5 meq L^{-1}. However, the HCO_3^- concentration increased significantly ($p<0.001$, $p<0.017$) in all soils after 200 days of irrigation at least up to 60%, which again decreased to levels slightly higher than the initial soils before irrigation (Fig. 5c). The values of CO_3^{2-} and HCO_3^- were less than Na^+, Ca^{2+} and Mg^{2+} cations (Fig. 4). The research findings support the observation of Paliwal *et al.* (1975) who stated that HCO_3^- ion enhanced the Na^+ ion uptake however decreased K^+, Ca^{2+} and Mg^{2+} uptake by wheat plants. They also found reduction in crop growth when the concentration of HCO_3^- exceeds 8 meq L^{-1} in irrigation water.

The TDW irrigation increased significantly the Cl^- (meq L^{-1}) concentration in soil A from 2.03-33.17 ($p<0.005$), in soil B from 1.92-29.23 ($p<0.01$) and in soil C from 3.09-25.17 ($p<0.07$, 0.034) (Fig. 6a). After 458 days of TDW irrigation, the concentrations of Cl^- dropped significantly ($p<0.001$, $p<0.004$) in all the soils slightly below the initial levels before irrigation.

The mean concentration of SO_4^{2-} increased significantly ($p<0.000$, 0.005) in A, B and C soils from an average value of 4.34-13.04, 4.41-13.70 and 2.45-3.90 me L^{-1}, respectively (Fig. 6b). After 458 days of TDW irrigation, the SO_4^{2-} concentration decreased significantly below the initial levels of soils with an average value of 0.14 me L^{-1} ($p<0.001$), 0.27 me L^{-1} ($p<0.001$) and 0.1 me L^{-1} ($p<0.001$).

The main important anions in this study were CO_3^{2-}, HCO_3^-, Cl^-, SO_4^{2-}. Because, these have different effects on soils particularly in relation to the cation exchange capacity where the ion exchange takes place and can change the ratio of adsorbed cations. This includes for example, the ratio of Na^+ to Ca^{2+} cations. The results agree with Ramzan and Nye (1978) who stated that though SO_4^{2-} ion has no direct effect on soil chemistry, it contributes to increase salinity in the soil solution. Cl^- also is a common anion, which has a direct toxic effect on some plants but is a significant factor that

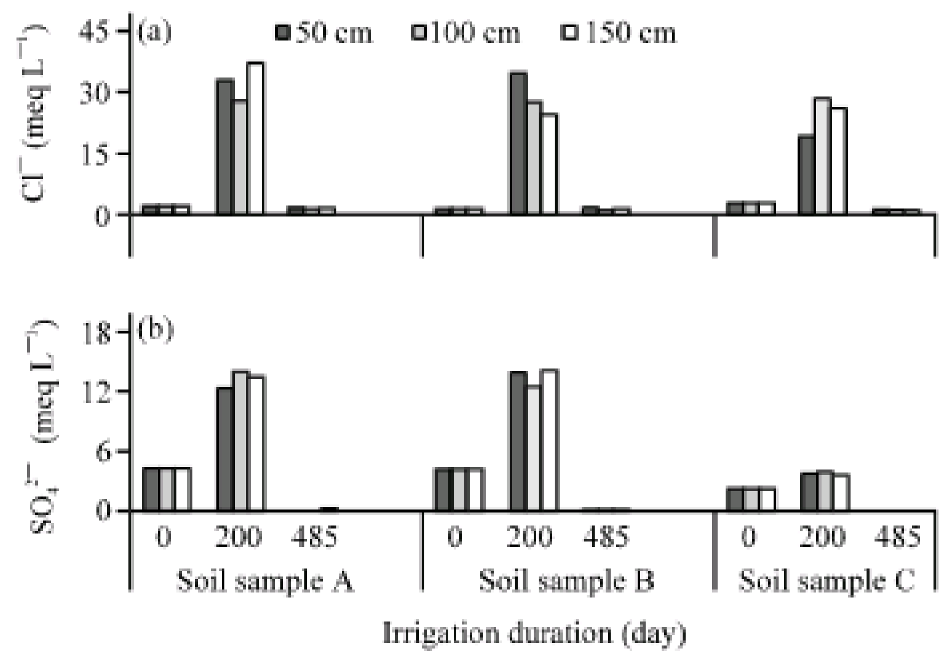

Fig. 6: Effect of irrigation duration on Cl^- (a), SO_4^{2-} (b) profiles of three soils (A, B and C) by soil depth

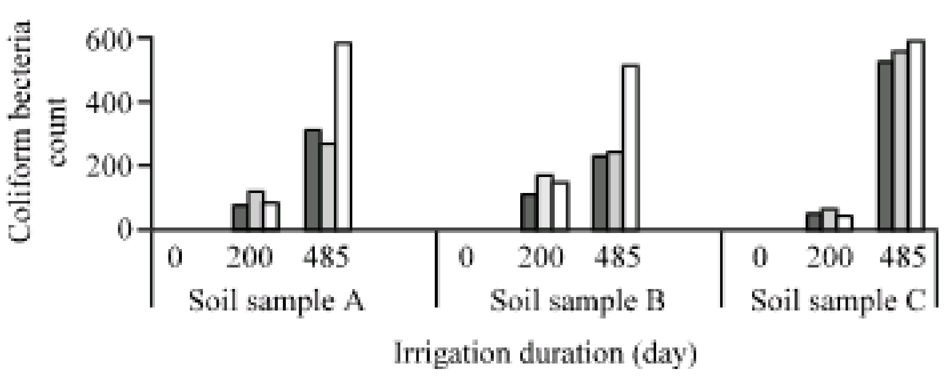

Fig. 7: Distribution of coliform bacteria in three soils (A, B and C) irrigated with TDW

contributes to salinity of soil. CO_3^{2-}, HCO_3^- are the major factor for controlling the soil pH and hence controlling the uptake of ions by plant roots.

Impact of TDW on microorganisms in soils: Normally, the domestic wastewater contains large quantities of organic materials than the normal water and is expected to enhance microbiological activities including the microbial proliferation which may cause environmental risks. Microbial investigation showed that the original soil samples (before irrigation) did not contain coliform bacteria or *E. coli*. However, continuous irrigation with TDW, all the soils showed only the presence of coliform bacteria after 200 and 458 days of irrigation (Fig. 7). The average number of bacteria in soil A, B and C after 200 days and 458 days of TDW irrigation were 99 and 393 cells, 149 and 333 cells and 56 and 559 cells, respectively. In addition to the above, the microbial analysis indicated that *E. coli* was absent in all the soils irrigated with TDW.

CONCLUSIONS

This study indicated that TDW did not affect significantly the soil texture, physico-chemical properties and the micro-organism counts up to 458 days of the irrigation with treated domestic wastewater. Relatively non-significant effect of TDW irrigation on soil physio-chemical properties suggests that due to predominantly sandy nature of soils, the effect of TDW was less prominent due to low cation-exchange-capacity and low water holding capacity of soils. The study highlighted the importance of reusing the treated domestic wastewater for irrigation especially for landscape development with minimal environmental hazards and to increase water use efficiency of the available water resources.

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