INTERNATIONAL JOURNAL OF AGRICULTURE & BIOLOGY
ISSN Print: 1560–8530; ISSN Online: 1814–9596
10–039/AWB/2010/12–5–707–712
http://www.fspublishers.org

Full Length Article

Potential Impacts of Industrial Reclaimed Water on Landscape Irrigation

MAQBOOL AHMAD[1], AHMAD SAEED BAJAHLAN[1] AND KHALID ABDULLAH AL-HAJERY[1]
Environmental Control Department, Royal Commission for Jubail and Yanbu P.O. Box 30191, Yanbu Al-Sinaiyah, Kingdom of Saudi Arabia
[1]Corresponding author's e-mail: maqbool_60@hotmail.com; bajahlan@rcyanbu.gov.sa; hajery@rcyanbu.gov.sa

ABSTRACT

Present study was conducted to check the feasibility of industrial reclaimed water (IRW) for irrigation purposes and its impact on plant growth and soil properties. Different types of grass, shrubs, ground cover and trees were grown in three experimental plots. Each plot was subdivided into three subplots for shrubs, ground cover and trees. Plot A was irrigated with industrial reclaimed water (IRW), plot B with (50/50) mixture of both IRW and treated sewage effluent (TSE) and plot C with TSE. Results showed that IRW is highly saline with high sodium (914 mg/L), SAR (42.8) and TDS (3054 mg/L) as compared to TSE (Na 220 mg/L, SAR 8.6 & TDS 1081 mg/L). Plants irrigated with IRW and mixture of IRW and TSE (50/50) indicated mortality rate of 57% and 12% respectively, while plants irrigated with TSE have only 4% mortality. Soil analysis reconfirmed the residual harmful effects of IRW on soil properties as indicated by substantial increase in pH from 8.56 to 10.72, carbonate and bicarbonate from 243 to 728 mg/kg and alkalinity from 220 to 800 mg/kg in soil irrigated by IRW. Notably mortality rate of some salt resistant varieties was less than others. It is concluded that pure IRW is not suitable for irrigation purposes, while mixture of TSE/IRW (50/50) may be fit for salt tolerance varieties. Industrial reclaimed water can be used if the quality of IRW is further improved at industrial wastewater treatment plant or some other amendment techniques as wash down the salts with TSE from root zone.

Key Words: Wastewater; Treated sewage effluent; Alkalinity; Sodium adsorption ratio; Conductivity

INTRODUCTION

With increasing pressures on water resources, the concept of beneficial use of treated wastewater has rapidly become imperative for water agencies around the world. Water reclamation, recycling and reuse are now recognized as key components of water and wastewater management. With the technological advances in wastewater treatment, the opportunity for water reuse has been more viable. The benefits of using recycled water include protection of water resources, prevention of coastal pollution, recovery of nutrients for agriculture, augmentation of river flow, savings in wastewater treatment, groundwater recharge and sustainability of water resource management (Angelakis & Bontoux, 2001; Xuan & Xu, 2009). Moreover, wastewater use schemes, if properly planned and managed, can have positive environmental impact, besides providing increased agricultural yields (Qadir *et al.*, 2010).

The available surface water and groundwater resources in the Kingdom of Saudi Arabia are not sufficient to meet increasing demand. To supplement the deficit in water balance there is a growing interest in reuse of reclaimed water. The Kingdom's policy is to use all available treated wastewater particularly for agriculture. Treated wastewater is partially used in irrigation, while the remaining is discharged to land, disposed to sea and is also reused for industrial purposes, groundwater recharge and landscape (Abu Rizaiza, 1999). Near Riyadh, date palms and forage crops are irrigated using tertiary treated wastewater effluents. Wastewater is also reused for irrigating landscape plants, trees and grass in municipal parks in several cities, such as Dhahran, Jeddah, Jubail, Riyadh, Taif and Yanbu Al-Sinaiyah (Hussain & Saati, 1999; EPA 625/R, 2004; Chowdhury *et al.*, 2006).

Yanbu Al Sinaiyah is one of the two major industrial cities of Kingdom of Saudi Arabia, established by Royal degree in 1975 and subsequently operated under the auspices of the Royal Commission. The city has been an integral element in the kingdom's goals of economic and geographical diversification. The petrochemical industries form the economic base and have provided a catalyst for growth in the country. Royal Commission provides all the basic infrastructure and utilities to facilitate the industrial growth. There are two biological treatment plants for industrial and sanitary wastewater. The sanitary wastewater treatment plant is designed to treat an average flow of 27000 m^3/day and industrial wastewater treatment plant has the capacity of 24000 m^3/day. Currently, the treated sewage

To cite this paper: Ahmad, M., A.S. Bajahlan and K.A. Al-Hajery, 2010. Potential impacts of industrial reclaimed water on landscape irrigation. *Int. J. Agric. Biol.*, 12: 707–712

water (TSE) production is approximately 20765 m^3/day and industrial reclaimed water (IRW) 17500 m^3/day. The effluent of the sanitary wastewater treatment plant (SWTP) is called treated sewage effluent (TSE). TSE is used to irrigate landscaped areas within the city except private residences, mosques, health facilities, schools, children's play areas and surface spray areas. These areas are irrigated with potable water.

Royal commission goal is to save potable water and use TSE for irrigation at all places. In this case TSE will not be sufficient to meet the requirement of whole city irrigation system. To overcome this deficiency industrial reclaimed water (IRW) is planned to mix with TSE to fulfill the requirements of irrigation system. Presently IRW is partially used by the industry for equipment cleaning and for close circuit cooling water. The system also provides make-up water for the fire fighting in the primary industrial zone and surplus is discharged to the sea.

In many countries, industrial wastewater is often mixed with the municipal wastewater to use for irrigation purposes. Reports show that industrial treated wastewater from textile, refinery and petrochemical are used for irrigation without any detrimental effect on crop and soil (Aziz *et al.*, 1995 & 1996). In Jubail industrial city IRW is mixed with TSE and used successfully for landscape purposes. However, sodium and other forms of salinity are the most persistent in recycled water and are among the most difficult to remove from water. The salinity of recycled water can influence both the soil and the growth of the crops being irrigated. Salinity in the form of sodium ions can directly affect soil properties through the phenomena of swelling and dispersion (Halliwell *et al.*, 2001).

In order to check the feasibility of using IRW for irrigation purposes in Yanbu industrial city, a detailed study was conducted with the coordination of Royal Commission Road and Landscaping Department. The objectives of this study were to (a) check the feasibility of using IRW in irrigation and (b) identify any adverse effect of IRW on soil properties and plants growth.

MATERIALS AND METHODS

Water quality treatments: These treatments were: 100% industrial reclaimed water (IRW), mixture of IRW and TSE (50/50), 100% treated sewage effluent (TSE), which acted as control.

Landscape model design and irrigation system: The following plants were grown as test species and irrigated as per plan presented in Fig. 1

Trees: *Delonix regia* (*DR*), *Ficus nitida* (*FN*), *Rosea alba* (*TR*)

Shrubs: *Acalypha yellow* (*AY*), *Ixora macrotyrsa* (*IM*), *Ixora coccinea* (*IC*), *Pseuderanthemum* sp. (*PA*), *Duranta repen* (*DR*), *Gardenia jasminoides* (*GJ*)

Ground Grass: *Asparagus sprengeri* (*AS*), *Alternanthera bettzickiana* (*AB*), *Jasmium sambac* (*JS*), *Alternanthra versicolor* (*AV*), *Allamanda cathartica* (*AC*), *Euphorbia keysii* (*EK*)

Grass: Bermuda grass.

Experimental site was selected between industrial wastewater treatment plant and sewage treatment plant, so that both TSE and IRW could be easily managed. Three identical plots of lands (18 x 6.5 m) 5.0 m. away from each other were selected and named as plot A irrigated with 100% IRW, plot B irrigated with 50% IRW and 50% TSE and plot C irrigated with 100% TSE. Each plot was further subdivided into three subplots for trees, shrubs and ground cover. Three separate small plots of 3 × 3 m area with each main plot were used for grass cultivation. Plot A (T-1) was irrigated with 100% IRW, plot B (T-2) with 50/50 of IRW and TSE and plot C (T-3) with 100% TSE and was used as control (Fig. 1).

Electrically controlled valves, gate valves, strainers, hard lines (PVC), soft lines (PE), water emission devices (sprinklers, bubblers, emitters) and other fitting and accessories were used for irrigation. Dip irrigation system was used for trees, shrubs and ground cover and sprinklers were employed for grass. All the three experimental plants were irrigated twice a day at the same time for one hour.

Analysis of water, plants and soil: Water samples were analyzed for conductivity, turbidity, pH, TSS, TDS, BOD, COD, oil and grease, Cl^-, TOC, calcium, magnesium, sodium and alkalinity by standard methods 20^{th} edition (Clesceri *et al*., 1998). Trace metals were analyzed using ICP by EPA method 200.15 (Martin *et al.*, 1994). Weekly determinations were made for plant height, trunk growth, crown growth, leaf color, number of young shoots, number of branches and mortality rate. Soil samples were analyzed for moisture, pH, conductivity, chloride, carbonate, bicarbonate, alkalinity and TOC (Rashid *et al.*, 2001). Metals like calcium, magnesium, sodium, potassium and other heavy metals were analyzed by EPA method 200.15 using ICP–OES (Vesta MPX Varian).

Sampling and statistical analysis: Grab samples of both TSE and IRW were collected twice a week and analyzed in central quality control laboratory. Total 160 samples were collected for TSE and IRW. For Soil analysis 18 (3 from each plot) samples from all the three plots were collected before starting the experiments and then at the end of the trials. The data were statistically analyzed for two-way ANOVA using COSTAT computer package to ascertain the significant difference (if any) among the various factors (sampling dates & waters).

RESULTS AND DISCUSSION

Water quality: Analysis of variance indicated significant differences in the sampling dates, water samples with significant interactions of these factors for all the physic-chemical characteristics except pH and turbidity, which

Fig. 1: Detailed landscape model design

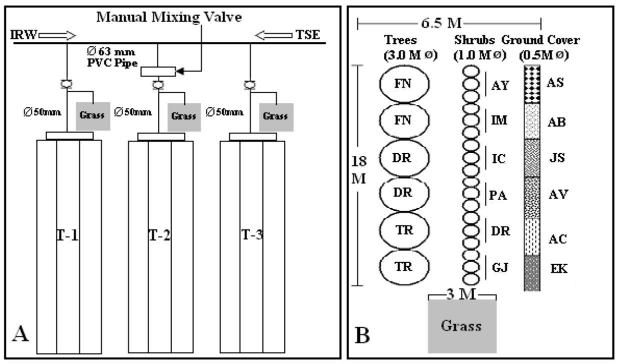
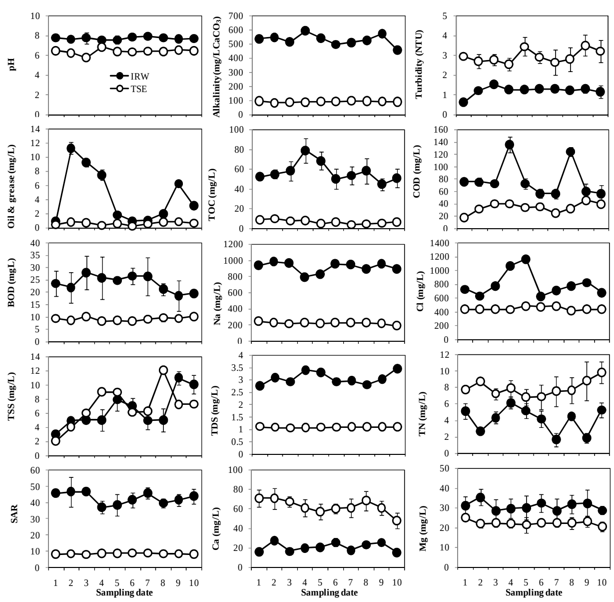


Fig. 2: Comparison of IRW and TSE for various physico-chemical characteristics



indicated no significant (P>0.05) difference in the sampling dates; Ca, which indicated no significant (P>0.05) interaction of sampling dates and water samples and BOD, SAR and Mg, which showed no significant (P>0.05) difference in sampling dates as well as non-significant (P>0.05) interaction of sampling dates and water samples. The basic criteria to evaluate water quality for irrigation purposes were: (a) relative proportion of sodium cations (Na^+) with bivalent cations (Ca^{2+} & Mg^{2+}), (b) Total dissolved salts (TDS) and (c) excessive concentration of elements that cause ionic imbalance in plants or toxicity. The first two criteria are the major concern in IRW especially high sodium and TDS (Richards, 1954) as these are the major causes of salinity.

Monthly average results with average and standard deviations for IRW and TSE are presented in Fig. 2. High values of standard deviation in IRW showed that quality of water was not persistent throughout the study period, while TSE had low standard deviation. This indicated that water quality was almost same throughout the study period. Comparisons of important parameters like TDS, SAR, sodium, pH and alkalinity for IRW and TSE showed that IRW has high pH, chloride, TDS, sodium and sodium adsorption ratio (SAR) as compared to TSE (Fig. 2). These parameters categorize IRW as moderately saline water with high Na^+ contents and which may not be suitable for sensitive crops and pose some negative effects on plant growth and soil texture (Bond, 1998). Generally SAR value greater than 10.0 is considered detrimental to soil characteristic and sensitive plant growth (Richards, 1954). The quality of TSE was persistent as compared to IRW and no violation was recorded from irrigation water standards (RC Regulations, 2004). Based on pH, TDS, SAR and conductivity TSE is categorized as very good for irrigation purposes (Fig. 2).

In IRW pH always exceeded 7.5, while TSE have pH less than 7.5, making IRW unfavorable for nutrient uptake. Similarly Na^+ contents of IRW were much higher (914 mg/L) than TSE (220 mg/L). Results also showed that IRW had much higher SAR values (42.8) as compared to TSE (8.6). High SAR was due to high Na^+ and less $Ca^{2+}$and Mg^{2+}. Prolonged use of water with high salt and sodium may destroy soil texture (Hussain *et al*., 2002). Higher TDS are generally not good for plants growth and IRW has high TDS as compared to IRW (3.054 & 1.081 mg/L, respectively). Generally grass required a low TDS for optimum growth and development hence making IRW unfavorable for grass and other sensitive crops. Tip burning effect was prominent in grass irrigated with IRW. This explained why more death of plants occurs in 100% IRW. The yellowing of leaves was due to the deficiency of nutrients at a higher pH. There was no great difference in trace metals contents of TSE and IRW except iron (data not shown).

Organic matter had no direct effect on the quality of irrigation water. Indirectly it can reduce the effect of sodium hazards. In the present study organic contents were also measured in the form of COD, O&G, TOC and BOD. The organic contents in TSE were much lesser than IRW. No violation from RC irrigation standards was recorded. Maximum COD recorded for IRW and TSE were 136 and 45.6 mg/L, respectively. Average values of COD were 78.3 mg/L for IRW and 34.0 mg/L for TSE. Results showed that both in IRW and TSE O&G values were less than irrigation water standards. Comparatively O&G was higher in IRW than TSE. In IRW it varies from 0.9 to 11.2 mg/L, while in TSE it ranged from 0.18 to 0.8 mg/L. Thus in IRW further treatments are required to reduce organic contents to meet irrigation water standards.

Plant growth: In these studies plants irrigated with 100% TSE were used as control and considered to attain 100% growth. Average plants growth data for plant height, plant crown and plant trunk is given in Table II. Growth of plants in 100% IRW and 50% IRW+50% TSE was compared with plot 100% TSE. Plant growth pattern and physical

Table I: Analysis of variance (significance of variance sources) of IRW and SWE water samples at various sampling dates

SOV	df	pH	Alkalinity	Turbidity	O & G	TOC	COD	BOD	Na	Cl	TSS	TDS	TN	SAR	Ca	Mg
Date (D)	9	NS	**	NS	**	**	**	NS	**	**	**	**	**	NS	**	NS
Waters (W)	1	**	**	**	**	**	**	**	**	**	*	**	**	**	**	**
D x W	9	*	**	*	**	**	**	NS	**	**	**	**	**	NS	NS	NS

Significant at **, P<0.01; *, P<0.05 and NS, non-significant (P>0.05)

Table II: Comparison of plant growth and death rate of tree, shrubs and ground cover in 100% IRW, 50% IRW + 50% TSE and 100% TSE

Treatment	Trees	Shrubs	Ground Cover	Average	%
		Plant height growth (mm)			
100% IRW	13.70±4.37	5.90±1.33	8.75±2.53	9.45±2.28	35.16
50/50 IRW & TSE	30.82±7.96	10.64±0.58	12.40±1.40	17.95±6.45	66.79
100% TSE	46.49±8.12	15.70±3.31	18.45±1.45	26.88±9.84	100.00
		Plant Crown growth (mm)			
100% IRW	45.20±6.89	25.40±15.12	9.30±8.3	26.63±10.38	52.95
50/50 IRW & TSE	70.50±3.79	32.80±10.30	14.70±8.41	39.33±16.44	78.20
100% TSE	93.20±11.77	37.60±9.53	20.10±11.17	50.30±22.04	100.00
		Plant trunk growth (mm)			
100% IRW	0.68±0.45	0.32±0.09	0.36±0.11	0.45±0.11	78.16
50/50 IRW & TSE	0.81±0.43	0.36±0.09	0.36±0.04	0.51±0.15	87.93
100% TSE	0.88±0.26	0.46±0.85	0.40±0.16	0.58±0.15	100.00
		Dead plants (%)			
100% IRW	8.0±1.2	20.0±0.92	88.00±4.70	38.67±24.91	58.59
50/50 IRW & TSE	3.0±0.58	10.0±0.67	11.00±0.65	8.00±2.52	12.12
100% TSE	0.0	1.0	5.00±0.48	2.00±1.53	3.03
		Wilted plants (%)			
100% IRW	5.0±1.2	14.0±0.61	55.0±3.31	24.67±15.39	37.37
50/50 IRW & TSE	5.0±0.33	9.0±0.43	17.0±0.79	10.33±3.53	15.66
100% TSE	2.0±0.67	4.0±0.33	5.0±0.31	3.67±0.88	5.56

Total trees = 18, total shrubs = 36 and total ground cover =144. Total plants = 198

Table III: Soil analysis before (B) and after (A) treatment

Parameters	100% IRW		50/50 IRW & TSE		100% TSE	
	B	A	B	A	B	A
Moisture %	2.43±0.18	10.83±0.48	2.66±0.19	11.19±0.57	2.51±0.17	10.28±1.00
pH	8.56±0.06	10.72±1.10	8.48±0.30	9.05±0.25	8.60±0.15	8.40±0.59
Conductivity (dS/m)	0.98±0.07	3.12±0.17	0.99±0.06	2.45±0.06	0.98±0.05	0.94±0.06
Chloride (mg/kg)	343.50±4.75	1030.40±12.35	228.90±2.27	686.90±5.86	228.90±2.11	458.00±11.85
CO_3^{2-} (mg/kg)	60.00±6.19	240.00±3.79	60.00±1.09	120.00±2.73	61.00±2.30	45.00±3.48
HCO_3^- (mg/kg)	183.00±3.99	488.00±10.17	184.00±3.40	183.00±2.52	182.00±4.10	184.00±4.26
Alkalinity (mg/kg, $CaCO_3$)	220.00±5.06	800.00±10.14	200.00±4.84	350.00±7.42	200.00±5.55	200.00±6.39
TOC (mg/kg)	701.00±7.37	456.00±11.84	646.00±4.63	405.00±5.13	620.00±4.81	930.30±9.56
SAR	1.18±0.05	4.45±0.19	1.03±0.09	2.24±0.07	1.03±0.05	0.98±0.11
Ca (mg/kg)	3592.05±19.60	3950.10±18.18	3536.70±6.96	3552.95±11.14	3659.40±9.60	3835.00±10.60
Mg (mg/kg)	2949.70±18.46	3241.35±7.51	2959.75±13.68	3113.95±16.44	3047.95±15.87	3079.80±14.17
Na (mg/kg)	395.90±8.02	1565.20±11.85	344.60±8.21	661.75±8.11	351.09±8.41	338.92±6.69

observation indicate that irrigation with pure IRW has adverse impact on plant growth. Plant growth in plot B (T-2) and irrigated with 50/50 TSE and IRW was much better than with 100% IRW. Lowest plant height increase was recorded in plot 100% IRW (average, 9.45 mm) compared to 50/50 TSE and IRW (average, 17.95 mm) and 100% TSE (average, 26.89 mm) (Table II). Considering plant height as growth marker, growth in plot 100% IRW was 35.14% in 50/50 TSE and IRW 66.7% as compared to 100% TSE, which attained 100% plant height growth. Therefore, based on this particular growth indicator IRW cannot be recommended to use for irrigation. Even sensitive plants in 50/50 TSE and IRW did not show healthy growth as compared to 100% TSE.

Plant crown growth was also measured and compared with plant in 100% TSE. Plants grown in 100% IRW had a plants crown growth rate average of 26.63 mm (53%), while 50/50 TSE and IRW attained 39.33 mm (78%) as compared to 100% TSE, which attained plant crown growth 50.30±20.04 mm (100%). Again using crown as a growth indicator plot 100% IRW is not recommended since their treatment averages was much lesser than plot 100% TSE. Plant crown growth in 50/50 TSE and IRW was much better than 100% IRW but not as good as in 100% TSE (Table II).

Similarly plant trunk growth also showed less growth in 100% IRW and 50/50 TSE and IRW as compared to 100% TSE.

Numbers of dead plants were also counted in all the three plots. Maximum plants were died in 100% IRW (58.6%) and minimum in 100% TSE (3.5%). In 50/50 TSE and IRW mortality rate was 12.12% much lesser than 100% IRW. Death rate in 50/50 TSE and IRW varies from species to species. In trees highest death rate was noted in *FN* (33%), while minimum was for *DR* (0%). This indicated that *DR* is a tolerant species, which can grow in diluted IRW (Table II). Similarly, among shrubs *IC* and *PA* had 0% death rate. The same trend was also noted in ground cover. This indicated that salt tolerant species can be grown in 50/50 TSE/IRW, while it is not suitable for sensitive varieties (Table II). These results show that death rate is considerably reduced in 50/50 TSE and IRW indicating that with some amendment, IRW can be used for resistant varieties.

Similarly comparison for wilted plants in all the three experiments showed that welting was the maximum (37.4%) in 100% IRW, while it was only 5.6% in 100% TSE. In 50/50 TSE and IRW this figure was moderate and only 15.7% plants were welting (Table II). Other normal growth indicators like number of young shoots, number of cluster of leaves, number of dead branches and color of leaves are also very important. These results affirm the true advantage of using TSE as main source of irrigation. In 100% TSE, highest numbers of clusters of leaves, young shoots were recorded and wilted plants, dead shoots and dead plants were lowest. High salinity and high SAR makes IRW unsuitable for irrigation purposes (Kijne *et al.*, 1998; Hussain *et al.*, 2002).

Soil analysis: Two sets of soil samples in triplicate from all the three plots were collected, one before irrigation and the second at the end of these studies. All the samples were analyzed for moisture, pH, conductivity, chloride, carbonates, bicarbonates, total alkalinity, total organic carbon, SAR and trace metals (Table III & IV). These results reaffirm the residual harmful effect of IRW on the properties of soil as indicated by a substantial increase of pH in 100% IRW from 8.56 to 10.72. Similar pattern was observed in 50/50 TSE and IRW and pH increased from 8.48 to 9.05. The increase in pH in 50/50 TSE and IRW was much lesser than 100% IRW. In contrast, 100% TSE did not show negative effect on the soil properties with an initial pH of 8.6 and 8.4 after irrigation. A similar increase with negative effect on soil properties was reflected by other soil parameters namely alkalinity, carbonate, bicarbonate, conductivity, SAR and Cl^- (Table III). In 50/50 TSE and IRW increase in all above parameters was not significant.

Sodium (Na) is a prominently negative factor for soil properties (Bauder & Brock, 2001; El-Sawaf, 2005). Table III shows a drastic increase of Na contents of plot 100% IRW applied soil samples, 50/50 TSE and IRW had medium increase, while 100% TSE exhibited a minimal increase from 351.09 to 338.92 mg/kg. This suggested that longer the soil is irrigated with IRW greater the physical properties of soil deteriorate (Hussain *et al.*, 2002). This is clearly indicated by increase in SAR in 100% IRW (from 1.18 to 4.45) and Hussain *et al*. (2002) (from 1.03 to 2.24). This effect can be minimized by alternatively irrigating with pure TSE, as suggested recently by Najafi *et al.* (2010).

These results indicated that IRW has tendency for increasing sodium and other salts in soil. High pH value also indicated that salt concentration in 100% IRW applied soil increased. Generally Na^+ and pH adversely affect soil properties for irrigation system (Hussain *et al*., 2002). At high level of sodium relative to divalent (Ca^{2+} & Mg^{2+}) in the soil, clay minerals in soil tend to swell and disperse and aggregates tend to slake. Weather from slaking, swelling or from the clay dispersion, the permeability of the soil is reduced and the surface become more crusted and compacted under such conditions. Thus, the ability of soil to transmit water can be severely reduced by excessive sodicity (effect of sodium & pH). This also increases the infiltration rate of soil and leaching efficiency reduced drastically (Bauder & Brock, 2001). Excess salinity within the plant root zone has a general deleterious effect on plant growth. These effects and some of the consequences of high sodium are discussed in details in the literature (Balks *et al.*, 1998; Halliwell *et al*., 2001; Surapaneni & Olsson, 2002). This entire phenomenon was prominent 100% IRW and to some extent in 50/50 TSE and IRW also and plants are badly affected by IRW. Even 50/50 mixing of IRW and TSE did not show healthy plant growth as was observed in 100% TSE. Growth inhibition in 50/50 TSE and IRW is much lesser than in 100% TSE and deterioration of soil is also minimal (Najafi *et al*., 2010).

CONCLUSION

Pure IRW cannot be used as a source of irrigation as it is not suitable to acceptable levels of plants growth and development. Growth data suggested that if IRW is used with TSE, it can be used to grow salt tolerant plants. To reduce the impact of IRW, salt accumulated from IRW can be washed with TSE. Problem of high pH can be solved by reducing the water pH at source. TSE, being more nutritive than IRW, may also improve plant growth. Thus to improve the quality of IRW, sources for high salt contents and high SAR should be identified. Up-gradation of treatment plants should also be considered to improve the quality IRW. While using IRW with TSE for irrigation, frequent flushing of the soil with TSE should be done to prevent excessive salt accumulation.

REFERENCES

Abu Rizaiza, O.S., 1999. Modification of the standards of wastewater reuse in Saudi Arabia. *Water Res.*, 33: 2601–2608

Angelakis, A.N. and L. Bontoux, 2001. Wastewater reclamation and reuse in Eruption countries. *Water Policy,* 3: 47–59

Aziz, O., M. Manzar and A. Inam, 1995. Suitability of petrochemical industrial wastewater for irrigation. *J. Environ. Sci. Health,* 30: 735–751

Aziz, O., A. Inam, Samiullah and R.H. Siddiqui, 1996. Long term effect of irrigation with petrochemical industrial wastewater. *J. Environ. Sci. Health.,* 31: 2595–2620

Balks, M.R., W.J. Bond and C.J. Smith, 1998. Effects of sodium accumulation on soil physical properties under and effluent-irrigated plantation. *Australian J. Soil Res.,* 36: 821–830

Bauder, J.W. and T.A. Brock, 2001. Irrigation water quality, soil amendment and crop effects on sodium leaching. *Arid Land Res. Manage.*, 15: 101–113

Bond, W.J., 1998. Effluent irrigation- an environmental challenge for soil science. *Australian J. Soil Res.*, 36: 543–555

Chowdhury, S., P. Champagne and A. Sarkar, 2006. *Evaluation of Wastewater Minimization Strategies Using Fuzzy Techniques*. The IASTED Conference on Advanced Technology in the Environmental Field Lanzarote, Canary Islands, Spain February 6-8, 2006

Clesceri, L.S., A.E. Greenberg and A.D. Eaton, 1998. *Standard Methods for the Examination of Water and Wastewater,* 20th edition. American Health Association, Washington DC

El-Sawaf, N., 2005. Response of *Sorghum* spp. to sewage waste-water irrigation. *Int. J. Agric. Biol.*, 7: 869–874

EPA 625/R-04/108, 2004. *Guidelines for Water Reuse,* p: 725. September 2004

Halliwell, D.J., K.M. Barlow and D.M. Nash, 2001. A review of the effects of wastewater sodium on soil properties and their implications for irrigation systems. *Australian J. Soil Res.,* 39: 1259–1267

Hussain, G. and A.J. Al Saati, 1999. Wastewater quality and its reuse in agriculture in Saudi Arabia. *Desalination,* 123: 241–251

Hussain, I., L. Rashid, M.A. Hanjara, F. Marikar and W. Van Der Hoek, 2002. *Wastewater Reuse in Agriculture, Working Paper, 37*. International water Management Institute, Colombo, Sri Lanka

Kijne, J.W., S.A. Parthaper and M.C.S. Saharwat, 1998. *How to Manage Salinity in Irrigated Land: A Selective Review with Particular Reference to Irrigation in Developing Countries*. SWIM paper 2, International Water Management Institute, Colombo, Sri Lanka

Martin, T.D., C.A. Brockhoff and J.T. Creed, 1994. EPA Method 200.15. *Determination of Metals and Trace Elements in Water by Ultrasonic Nebulization Inductively Coupled Plasma-atomic Emission Spectrometry Revision 1.2*, EMMC Version

Najafi, P., S.H. Tabatabaei and K. Asgari, 2010. Evaluation of filtration and SDI application effects on treated wastewater quality index. *African J. Agric. Res.,* 5: 1250–1255

Qadir, M., D. Wichelns, L. Raschid-Sally, P.G. McCornick, P. Drechsel, A. Bahri and P.S. Minhas, 2010. The challenges of wastewater irrigation in developing countries. *Agric. Water Manage.*, 97: 561–568

Rashid, A., J. Ryan and G. Estefan, 2001. *Soil and Plant Analysis Laboratory Manual,* 2nd edition. ICARDA, Aleppo, Syria

Richards, L.A., 1954. *Diagnosis and Improvement of Saline and Alkaline Soil, Agriculture Handbook No. 60*. Issued by United State Department of Agriculture, Riverside, California

Royal Commission Environmental Regulation, 2004. *Regulations and Standards*, Vol. 1, pp: 56–59. Royal Commission Saudi Arabia

Surapaneni, A. and K.A. Olsson, 2002. Sodification under conjunctive water use in the Shepparton Irrigation Region of northern Victoria: a review. *Australian J. Soil Res.,* 42: 249–263

Xuan, X. and H. Xu, 2009. Use of Reclaimed Water in China: management issues and strategies. *Manage. Sci. Eng.,* 3: 20–25

(Received 23 January 2010; Accepted 12 July 2010)