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Full Length Research Paper

Treated wastewater and diluted seawater in Qatar – Alternative irrigation resources for date palm

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Qatar is a country with no surface water supplies while the groundwater is saline and unusable for many crops. However, there is ample supply of seawater, treated wastewater and industrial water. In the present study, four types of irrigation water: groundwater (GW) (EC ≈ 2.00 dSm^{-1}), treated wastewater, diluted seawater of electrical conductivity (EC) ≈ 10 dSm^{-1} and diluted seawater of EC ≈ 15 dSm^{-1} were applied to mature date palm trees for two years (2012 & 2013) and their effects on yield, fruit quality and soil characteristics including heavy metals were assessed. Experimental design was split plot with three replications. Results indicated that irrigation with treated wastewater affected neither the date palm yields and fruit quality nor the accumulation of minerals and heavy metals in comparison with groundwater. Hence, it could be an alternative source of irrigation. Diluted seawater either of 10 or 15 dSm^{-1} affected the date palm yields significantly (28 and 45 % decrease, respectively) and salinized the soil indicating that further dilutions will be required to bring seawater under safer usage. However, it is possible to use this water when diluted to a proper ratio of seawater and groundwater.

Keywords: Diluted seawater, treated wastewater, groundwater, irrigation, date palm

INTRODUCTION

Using untreated and partially treated wastewater for irrigation is being given consideration in arid and semi-arid regions and urban areas where unpolluted water is a limited resource and wastewater enriched with nutrients is an important source for farmers (WHO 2006).

Comparatively lesser yields of date palm demand conspicuous improvements in agronomic practices in addition to growing high yielding varieties in their native areas. Qatar is one of the world's poorest countries in terms of natural freshwater resources (Shomar 2014).

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There are no rivers, very limited rainwater, and limited replenishment of groundwater (GW). Probably the scarcity of good quality irrigation water coupled with soil and water salinity may be the biggest constraint for lower yields. Date palm growers are struggling to have good quality alternative sources of water as they depend mostly on the groundwater (GW) for irrigation. The GW is the main natural water resource in Qatar. The annual 58 Mm^3/y estimated renewable water in Qatar and the 29 Mm^3/y (ca. in 2014) are far below the annual withdrawal rates. The withdrawals in 2012 were estimated by 400 Mm^3/y. The withdrawal increased from 56.4 Mm^3/y in 1976 to 100 Mm^3/y in 1983 to 272 Mm^3/y in 2000 to 248 Mm^3/y in 2009, and was reported as 400 Mm^3/y in 2012 (almost 7 times the replenishment rate) (MoE 2009). Looking into the current abstraction, the GW might completely disappear within four years from now. Consequently, the increased pressure on water resources continues, and the reserves of GW are steadily being decreased. This over abstraction will not only lead to the depletion of GW resources but also reduction of water quality and the abandonment of agricultural farms. Using such water for irrigation will result in increasing the salinity of the soil. Substantial parts of GW reserves show salinity levels above the recommended threshold for irrigation. The brine produced by certain farm processes and discharged back into the ground also increases the salinity of the remaining GW (Darwish *et al*. 2014).The future climatic changes (Bino 2008) may also worsen the situation.

Therefore non-conventional water resources such as treated wastewater and seawater can be an excellent alternative for agricultural irrigation. However, before using wastewater, its quality for irrigation needs to be assessed such as total salt concentration and/or electrical conductivity of the effluent (ECe), concentrations of cations, such as Ca^{++}, Mg^{++} and Na^{+}, concentration of toxic ions, such as heavy metals, boron and Cl^{-}, concentration of trace elements (particularly those which are suspected of being phyto-toxic), concentration of nutrients, particularly nitrate-N and level of suspended sediments (FAO 2015). It is worth noticing that water with total soluble solids (TDS) between 1,500 and 3,500 ppm could be harmful to plants, while at TDS = 3,500 ppm, water is unsuitable for irrigation.

For this purpose, the salt tolerance of date palm varieties under different conditions of soil and climatic factors and the stage of growth has to be kept in mind. Ayers and Wescott (1985) reported that in general, minimum electrical conductivity (EC) for 100 % yield of date palm was 4.0 dSm^{-1}while there was no yield at EC of 32 dSm^{-1}. The respective values for irrigation water (ECiw) are 2.7 and 21.0 dSm^{-1}. Fifty percent reduction in yield can occur at EC of 18.0 dSm^{-1} and ECiw 12.0 dSm^{-1}. Salinity stress is usually associated with growth inhibition and yield reduction (Tester 2003; Tripler *et al*. 2011) due to the osmotic effect on water uptake, reduced water conductivity of the roots, disrupted ion homeostasis in cells, inhibited metabolism, damaged membranes, and diver-gence of energy to salt-protection (Greenway and Munns 1980; Frans *et al*. 1996; Tester 2003; Tripler *et al*. 2011). Date palms are more adapted to salinity stress compared to most cultivated trees with a threshold of 4 dSm^{-1} and a reduction of 3.6% yield per unit of EC (dSm^{-1}) (Maas and Hoffman 1990).

Imbalanced plant nutrition may occur indirectly as side effects of salinity in addition to direct osmotic and specific ion effects. Thus, the plants may suffer for need of certain essential nutrients on one side while toxicities of others may happen due to higher concentrations. A study conducted by Aljuburi and Maroff (2007) at Qatar University indicated that salinity in irrigation water reduced leaf and root Mn, Zn, Fe and leaf K, Ca, Mg concentrations and the ratio of K/Na and Mg/Ca, but increased leaf N and root and leaf P, Cu, Na and Cl concentrations.

The first study conducted under realistic field conditions found that crops irrigated with the water discharged from sewage treatment plants contains only low levels of prescription drugs and ingredients commonly found in antibacterial soaps, make-up, shampoos and other personal care products. These substances do not tend to accumulate in vegetables, including tomatoes and lettuce that people often eat raw and concluded that recycled sewage water can safely be used for crop irrigation (USDA 2013). However, still more studies are required to understand the specific effects.

The present study was undertaken to find alternative sources of irrigation for date palm like treated wastewater and seawater, and to assess the effects on yield, fruit quality and soil characteristics including heavy metals.

MATERIAL AND METHODS

Treatments and plant material

This experiment was carried out at research farm of the department of biology and environmental sciences, college of arts and science, Qatar University Campus for two years (2012-13) with the following treatments:

1. Groundwater available at the farm having EC ≈ 2.00 dSm^{-1}
2. Treated wastewater
3. Diluted seawater of EC ≈ 10 dSm^{-1} (seawater + groundwater = 1 + 4)
4. Diluted seawater of EC ≈ 15 dSm^{-1} (seawater + groundwater = 1 + 2)

Experimental design was split plot with three replications. Date palm plants of uniform age and size were selected and tagged. Uniform quantity of manure and N, P & K fertilizer was applied to meet nutrient requirements of plants. Measured quantity of water was applied through bubbler irrigation system to various plants per treatment every alternate day in summer (April to October) and after every two days in winter (November to March). Of course, frequency of irrigations varied according to the prevailing season. Normal agronomic practices to all plants including protection from pests and diseases were adopted.

Mass of fruit per plant was recorded. Sampling of flag leaves was simultaneous, followed by analysis for various parameters including heavy metals. Similar was the case of fruit samples. Subsequently, the analysis of soil was also carried out for various parameters. Statistical analysis at 5% level to evaluate significance of results was performed as well.

Data collection and analysis

Dry mass

The flag leaves from the treated plants were weighed immediately after cutting (fresh mass) and packed into a paper bag. The samples were dried in an oven at 65°C for 72 hours and reweighed for calculating dry mass.

Mineral analysis

Flag leaves from the treated plants were obtained for chemical analysis. The samples were rinsed twice in running tap water, once in HCl solution (1 ml L^{-1}), and finally in double-distilled water. Then the samples were oven-dried, ground and digested with 5 ml of reagent-grade nitric acid at 130°C. The volume of the digest was brought to 50 ml with distilled water and stored in the dark at 4°C. The $Na^+$and K^+concentrations were measured using atomic emission spectroscopy (ICP-AES, Arcos, Spectro, Kleve, Germany). The Cl^-ions were measured using a chloridometer (chloride analyzer 926, Corning, Medfield, MA, USA).

Analysis of soil samples

Soil pH was measured in soil-H_2O suspension (1:2.5, w/w) and electrical conductivity (EC) was measured in soil to water suspension (1:5) using an HI 9828 Multiparameter portable (HANNA instruments). Organic matter content was determined by the Walkley and Black procedure (Nelson & Sommers 1982). Total nitrogen (N) was determined using the Kjeldhal method (Black 1965). Available phosphorus (P) was measured by the molybdenum blue method calorimetrically (Olsen & Sommers 1982).

Analysis of heavy metals in plant and soil samples

Heavy metals such as lead (Pb), cadmium (Cd), nickel (Ni), cobalt (Co) concentrations in plant and soil samples were determined by atomic absorption spectrophotometry as described by Dávila et al. (2012).

Sodium adsorption ratio (SAR)

SAR, a widely accepted index for characterizing soil sodicity, which describes the proportion of sodium to calcium and magnesium in soil solution. The formula to calculate SAR is given below:
SAR = [Na] / SQRT {([Ca] + [Mg]) / 2 }

RESULTS AND DISCUSSION

The irrigation water in Qatar is scarce and cannot meet all the requirements of plants. There is no surface water available in the form of rivers, lakes and canals but only groundwater and seawater are available. An alternative source like treated wastewater is needed to be searched out.

Quality of irrigation waters of the experiment and general soil properties

Data presented in Table 1 and 2 indicated that all the three waters were saline having EC of more than 1.5 dSm^{-1}, which is the general critical limit for using such water for most of the crops. However, date palm is more tolerant than most of the fruit plants and harmful effects appear when EC of water is more than 3.0 dSm^{-1} (Ayers and Westcot 1985), especially when the soil is light in texture (sandy loam or loamy sand) and has excessive drainage, as the case was in current experimentation. There was no sodicity threat of these waters because sodium adsorption ratio (SAR) was lower than the critical limit (13) and residual sodium carbonate (RSC) was nil. There was also none of the other conspicuous problems like higher Cl or heavy metal content. Thus the irrigation water were only saline and without any other problem. These could be used safely for a few years in sandy soils with high drainage in local conditions of Qatar. However, long-term use might have potential problem of salinization of soils and decreasing yields.

Yield of date palm

Groundwater and treated wastewater did not significantly affect date palm yield (Figure. 1). However, seawater diluted four and two times (EC = 10 and 15 = dSm^{-1}, respectively) decreased the dates yield significantly (Figure. 1). Reductions in yields were cumulative and pronounced in second year (2013) by indicating 11% lesser yields. Results were statistically significant separately in both the years as well as means of two years. Yields were significantly lesser (28%) in diluted seawater of approximately EC of 10 dS m^{-1} compared with groundwater while the yield decreased by 45% when approximate EC of seawater was 15 dSm^{-1}. This EC of water was higher than the salt tolerance limit of date palm (Ayers and Westcot 1985 and Maas 1990). Both dilutions of seawater differed significantly. These decreases were due to lesser water and nutrient uptake, as indicated by flag leaf analysis (Figure. 2). Considering economical yield reduction of 50%, both diluted seawaters did not reach that level indicating that producing dates with diluted seawater (of these dilution ratio) is possible only up to two years as after two years the yield decrease may go higher than economical yields. Alternatively, wider dilutions comprising of lesser EC waters can increase the salt accumulation time or some management strategies be adopted. However, treated wastewater did not decrease the yields and could be a safer alternative irrigation source without any danger of heavy metal accumulation (Figure. 3).

Table 1. Analysis of irrigation waters used in the experiments. EC (electrical conductivity), TDS (total dissolved solvents), SAR (sodium adsorption ratio), RSC (residual sodium carbonate), pH and minerals were measured in campus tap water and campus treated wastewater of Qatar University.

Parameters	Qatar University (QU) Campus water	Qatar University (QU) Campus Treated Wastewater
EC (dSm^{-1})	1.97	2.17
pH	8.03	7.25
TDS (ppm)	1181	1302
CO_3^{-2} (me L^{-1})	Nil	Nil
HCO_3^{-1} (me L^{-1})	5.04	3.39
Cl^{-1} (me L^{-1})	8.45	12.76
SO_4^{-2} (me L^{-1})	6.66	11.03
Ca^{+2} (me L^{-1})	6.08	6.27
Mg^{+2} (me L^{-1})	5.46	3.73
Na^{+1} (me L^{-1})	8.2	16.68
K^{+1} (me L^{-1})	0.42	0.50
SAR	3.42	7.04
RSC (me L^{-1})	Nil	Nil

Table 2. Heavy metals concentration (mg L^{-1}) in the irrigation water used in the experiment.

Parameters	**Qatar University (QU) Campus water**	**QU Campus Treated wastewater**
Arsenic (As)	-	0.01
Nickel (Ni)	-	0.02
Boron (B)	-	0.05
Cadmium (Cd)	-	<0.01
Chromium (Cr)	-	Nil
Cobalt	-	Nil
Lead (Pb)	-	0.05
Lithium (Li)	-	Nil
Copper (Cu)	0.01	0.1
Iron (Fe)	1.1	3.0
Zinc (Zn)	1.2	2.0
Manganese (Mn)	0.01	0.1
Molybdenum (Mo)	<0.01	<0.01

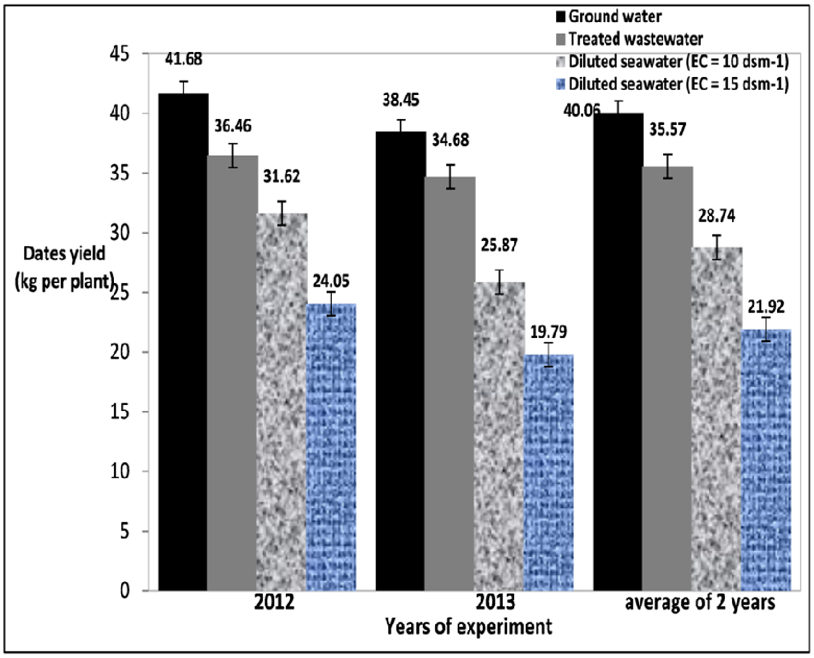

Figure 1. Effect of water treatment on yield of date palm. Ground water, treated wastewater, diluted seawater (seawater + groundwater = 1 + 4, EC ≈ 10 dS m^{-1} and diluted seawater (seawater + groundwater = 1 + 2, EC ≈ 15 dS m^{-1}) were applied through bubbler every alternative day in summer (April to October) and after every two days in winter (November to March) to date palm trees of uniform age and size. The trees were irrigated for 2 years (2012 and 2013) and average was taken with 3 replications in each experiment

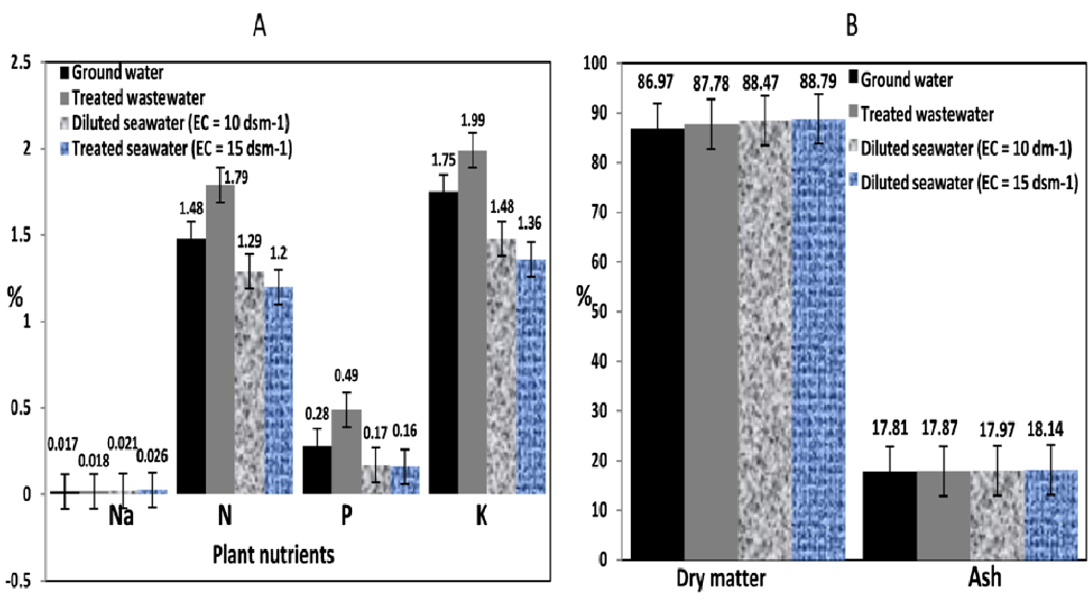

Figure 2. Biochemical analysis of flag leaf of date palm at fruit harvesting as a function of irrigation water salinity. A, Na, N, P and K analysis in %. B, Dry matter and ash contents in %. Results are mean of two years (2012 & 2013) and three replications.

Flag leaves analysis, fruit quality and accumulation of heavy metals

Flag leaves analysis (Figure. 2) revealed that water uptake by plants was disturbed by water that is more saline because more dry matter percentage was recorded in treatments of diluted seawater when compared to groundwater or treated wastewater. Uptake of N, P and K was also found decreased in flag leaves of plants treated with diluted seawater. Sodium accumulation in leaves was

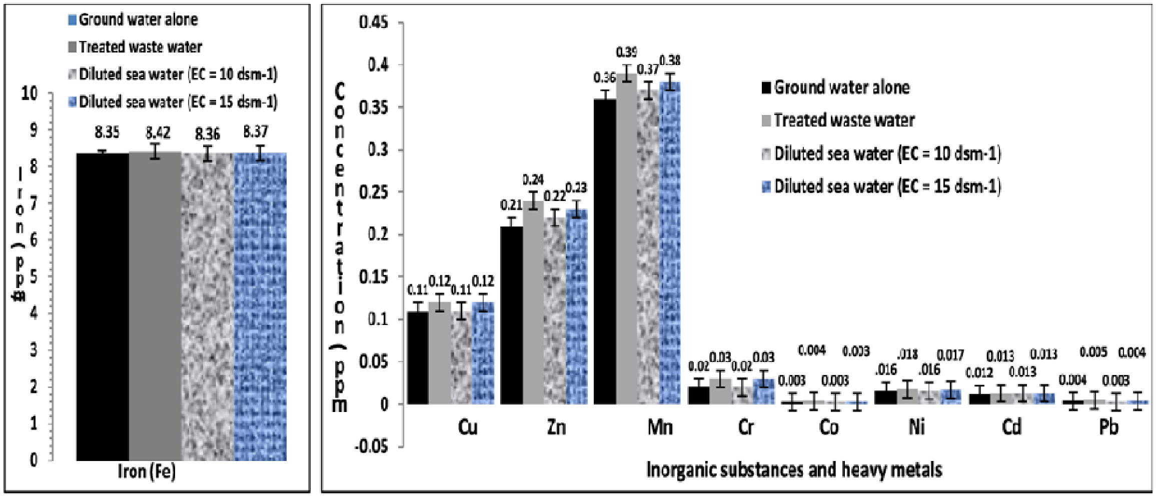

Figure 3. Analysis of flag leaf of date palm for heavy metals at the time of fruit harvesting as a function of irrigation water salinity. A, Cu, Zn, Mn, Cr, Co, Ni, Cd and Pb were measured in mg L^{-1} (ppm). B, Iron (Fe). Results are mean of two years (2012 & 2013) and three replications. All the parameters varied non-significantly due to treatments.

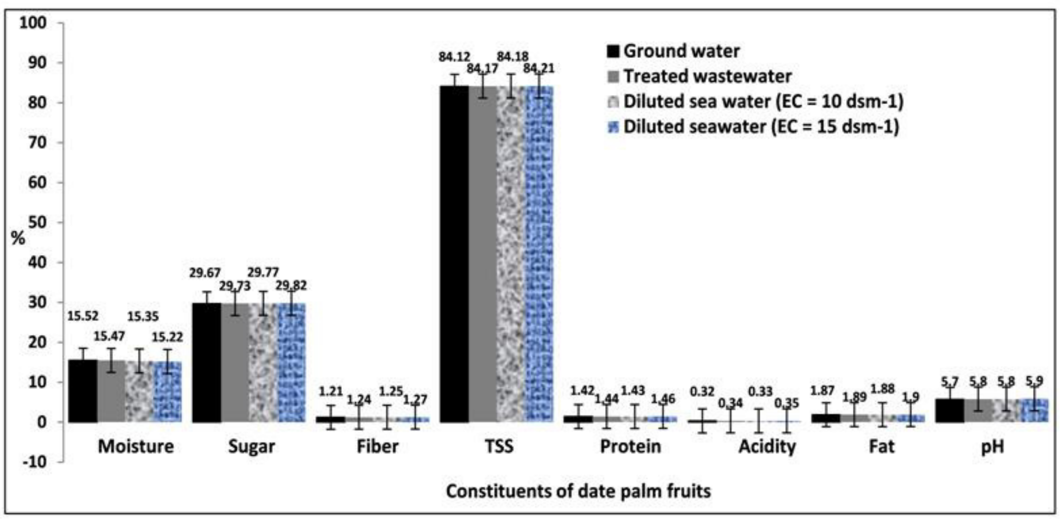

Figure 4. Analysis of date palm fruits quality for moisture, sugar, fibers, total soluble solids (TSS), proteins, acidity, fats and pH. Results are mean of two years (2012 & 2013) and three replications. All the parameters varied non-significantly different due to treatments.

not significantly different. Similarly accumulation of inorganic substances (Fe, Cu, Zn and Mn) and heavy metals (Cr, Co, Ni, Cd and Pb) in leaves was also found non-significantly different. Aljuburi and Maroff (2007) reported that nutrient concentration in date palm leaves was not affected at lower water salinity. Although, treated wastewater was used for irrigation in one of the treatment but no heavy metal accumulation was found because the numerical values in water were in permissible limits and excessive quantities, if any were removed during treatment of this type of water. Moreover, the soil was sandy with very good drainage, the chances of heavy metal were nominal.

Fruit (dates) quality and accumulation of heavy metals

One of the major objections when using treated wastewater/sewage is probable heavy metal accumulation and resulting deterioration of fruit quality in case of fruit plants including date palm. Therefore, assessing fruit quality and heavy metal accumulation is an integral part of this study. Data of Figure. 4 & 5 indicted neither threat of fruit quality deterioration nor accumulation of any heavy metal. All the quality parameters determined and heavy metal values recorded were within permissible limits as well as non-significant to groundwater treatment. Sugar, fiber, total soluble solids, proteins, acidity, fats and pH

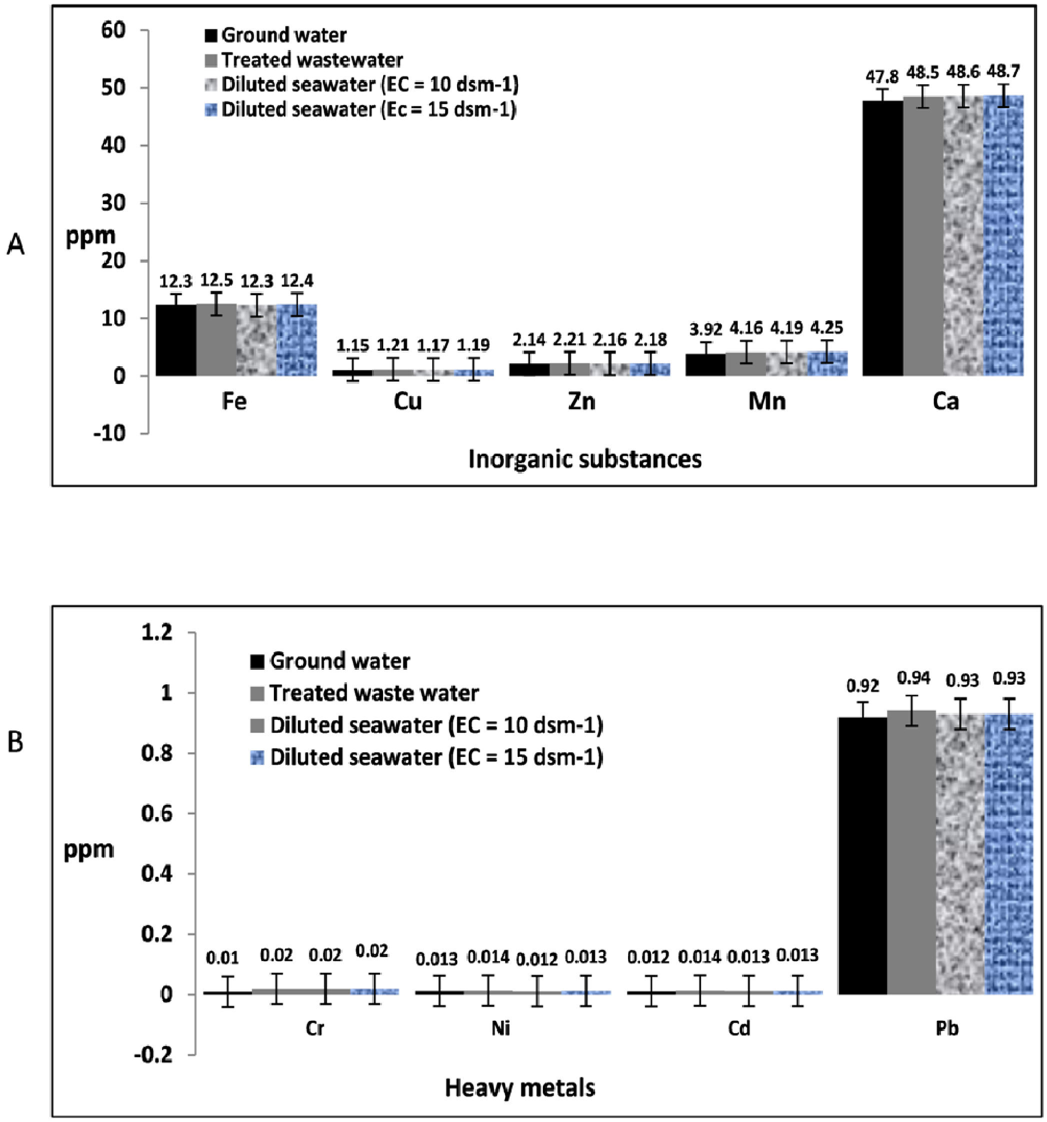

Figure 5. Analysis of date palm fruits (dates) for minerals (A) and heavy metals (B). Results are mean of two years (2012 & 2013) and three replications. All the parameters varied non-significantly different to treatments.

were within the allowed range. Values of Fe, Cu, Mn, Cr, Co, Ni, Cd and Pb were not found higher than the normal values. Similar values have been recorded by earlier workers as well (Al-Rawi and Al-Mohemdy 1975; Al-Khateeb *et al*. 1993; Erskine *et al*. 2004; Ghafoor *et al*. 2004 and El-Sharabasy *et al*. 2008).

General soil characteristics and the heavy metals

Soil characteristics are badly affected when irrigations with poor quality water continue for longer periods. In the present study, data (Figure. 6) indicated that organic matter, N, P and K contents of soil did not change much and the differences in treatments remained non-significant. Similar was the case of soil pH. However, soil EC and SAR of seawater treatments were found higher and significantly different (Figure. 6). The difference between groundwater and treated wastewater remained non-significant. Both concentrations of diluted seawater were significant to each other as well as groundwater and treated wastewater. The EC values exceeded the critical limit of 4 dSm^{-1} in both the treatments but SAR was still lower than the critical limit of 13. A soil with SAR greater than 13 is called a sodic soil. Excess sodium in sodic soils causes soil particles to repel each other and preventing the formation of soil aggregates. This results in a hard soil structure with poor water infiltration and aeration, and surface crusting, making tillage difficult and restricts seedling emergence and root growth (Munshower 1994; Horneck *et al*. 2007). This indicated soil salinization but not sodication. This effect

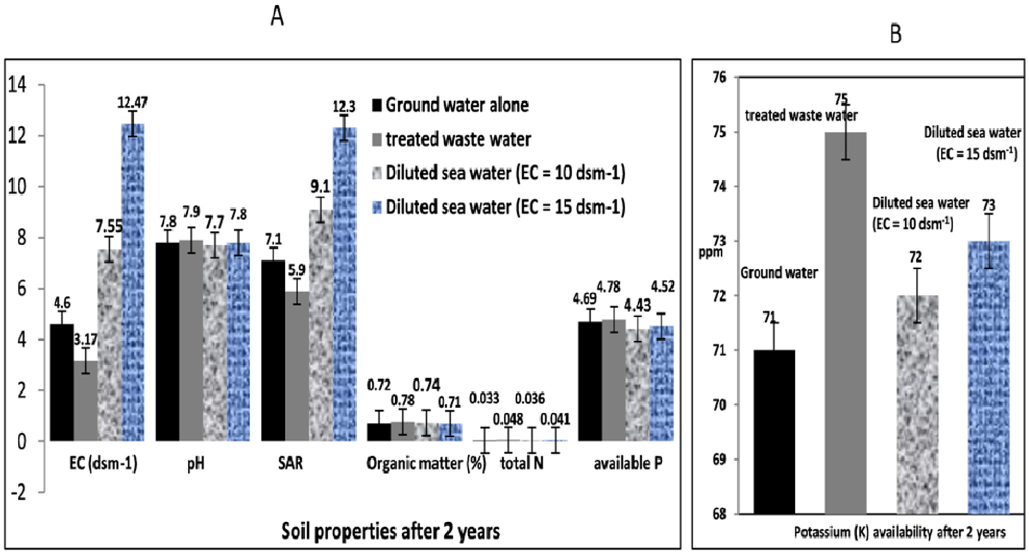

Figure 6. Soil parameters after two years (2012-13). EC and SAR were found significantly different. Organic matter (%), total N (%), available P (ppm) and K (ppm) were not different significantly. Results are mean of two years (2012 & 2013) and three replications.

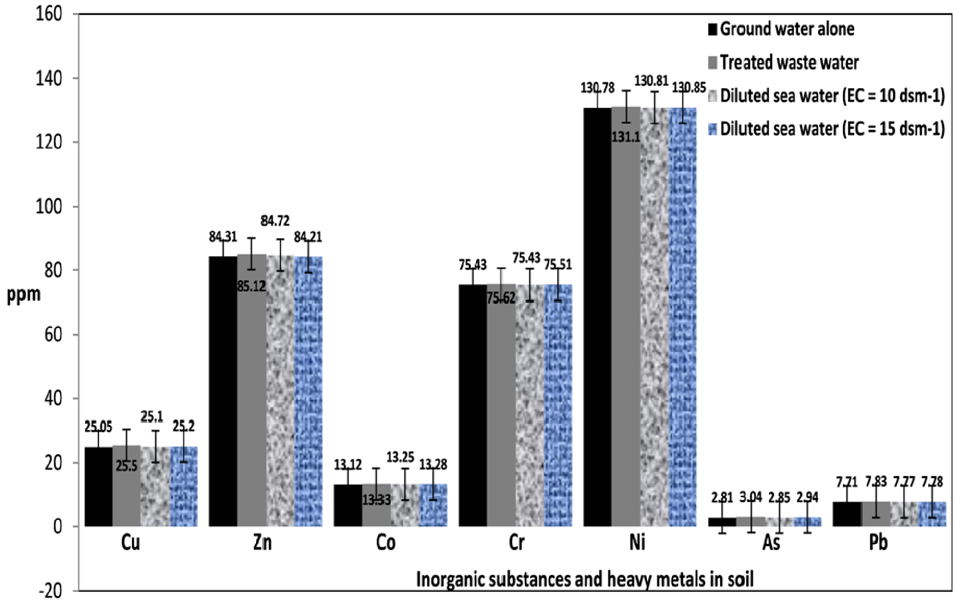

Figure 7. Analysis of minerals and heavy metals (Cu, Zn, Co, Cr, Ni, As, Pb) in soil irrigated with ground water, treated wastewater, diluted seawater (seawater + groundwater = 1 + 4, EC ≈ 10 ds m^{-1} and diluted seawater (seawater + groundwater = 1 + 2, EC ≈ 15 ds m^{-1}) for two years (2012-13). Results are means of three replications. The values are non-significantly different for treatments.

translated into yield decrements and comparatively lesser yields of date palm were recorded in these types of water (Figure. 1).

Considering the levels of heavy metals, it was clear that none of the irrigation water types caused accumulation of these metals (Figure. 7). Heavy metals may cause toxic effects at very low concentrations but fortunately, none of the value was beyond the critical values.

CONCLUSION

Irrigations with treated wastewater neither affected the date palm yields and fruit quality nor caused accumulation of heavy metals in comparison with groundwater. Hence, it could be taken as an alternative source of irrigation. Diluted seawater of either 10 or 15 dSm^{-1} significantly affected the date palm yields (28 and 45 % decrease, respectively) and salinized the soil indicating that a further dilution will be required to bring this water under safer usage. Nevertheless, these were still economical, as these were lesser than 50%, the critical value. The losses may increase in later years. However, it is possible to use this water when diluted with proper ratios of seawater: groundwater. No heavy metal accumulation was observed in leaves and fruits of date palm as well as the soil when seawater, groundwater and treated wastewater were used for irrigations.

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No competing interest

The authors of this manuscript have read and understood the policy of Water and Environment and declare that they have no competing interest.

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