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RESEARCH PAPER

Impact of reclaimed water irrigation on soil salinity, hydraulic conductivity, cation exchange capacity and macro-nutrients

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تأثير الري بمياه الصرف الصحي المعالجة على ملوحة التربة والتوصيل الهيدروليكي وسعة تبادل الكتايونات والعناصر المغذية الكبرى

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ABSTRACT. Field studies were conducted at Agriculture Research Center, Oman during the year 2010/2011 to monitor the impact of reclaimed water irrigation on soil physical and chemical properties after wheat, cowpea and maize cultivation (in rotation). Three different water sources (Groundwater (GW), desalinized water (DW), and Reclaimed Water (RW)) were used as the treatments in Randomized Completely Block Design (RCBD) with 3 blocks (replicates). Samples were taken from four depths (30, 45, 60 and 90 cm) after harvesting time of the three crops. Soil salinity (ECe) in all soil depths decreased with time. Organic carbon did not show significant difference between harvest timings of wheat and cowpea. Organic carbon increased with time in soil irrigated with reclaimed water. The saturated hydraulic conductivity of the soil, K_{sat} didn't show significant difference among the water types and their interaction with soil depths. Total nitrogen was the highest after cowpea harvest in reclaimed water irrigation. The soil phosphorus and potassium were not affected by any of the three water irrigation types. The highest concentrations of phosphorus and potassium were found to be in the upper soil layers. Overall, no adverse impacts of reclaimed water irrigation were observed after growing three crops of rotation.

KEYWORDS: Reclaimed water; soil salinity; hydraulic conductivity; CEC, macronutrients

المستخلص: أجريت مجموعة من الدراسات الميدانية في المديرية العامة للبحوث الزراعية والحيوانية بسلطنة عمان خلال العام ٢٠١٠/٢٠١١م بهدف رصد أثر مياه الري المعالجة من الصرف الصحي على عدد من خصائص التربة الفيزيائية والكيميائية بعد زراعة محاصيل القمح واللوبيا والذرة الشامية (بالتناوب). استخدمت ثلاث مصادر مختلفة من مياه الري (المياه الجوفية (GW) والمياه المحلاة (DW)، والمياه المعالجة (RW)) كمعاملات في تصميم القطاعات العشوائية الكاملة(RCBD) بثلاث مكررات. وتم أخذ عينات التربة من أربعة أعماق (٣٠، ٤٥، ٦٠ و ٩٠ سم) بعد حصاد كل محصول من المحاصيل الثلاثة. أشارت النتائج إلى أن ملوحة التربة (ECe) في جميع أعماق التربة قد انخفضت مع مرور الوقت. ولم يظهر الكربون العضوي أي فرق معنوي كبير بين توقيتي حصاد القمح وحصاد اللوبيا ووجد بأنه في ازدياد مع مرور الوقت في التربة المروية بالمياه المعالجة. فيما لم يظهر التوصيل الهيدروليكي المشبع (Saturated Hydraulic Conductivity) فرقا كبيرا بين أنواع المياه وتداخلها مع أعماق التربة. كان أعلى تركيز للنيتروجين بعد حصاد اللوبيا في التربة المروية بالمياه المعالجة في حين لم يتأثر تركيز الفوسفور والبوتاسيوم في التربة بأي من أنواع مياه الري الثلاثة. ووجد بأن أعلى تركيز للفوسفور والبوتاسيوم كان في الطبقات العليا من التربة وفي العموم لم يلاحظ أي آثار ضارة من مياه الصرف الصحي المعالجة وذلك بعد ري الثلاثة محاصيل والتي تم زراعتها بالتناوب.

الكلمات المفتاحية: المياه المعالجة ، ملوحة التربة ، التوصيل الهيدروليكي ، سعة تبادل الكاتيونات ، العناصر الكبرى

Introduction

The Sultanate of Oman is an arid country, with annual rainfall around 100 mm per year, requiring alternative water resources for irrigation. Reclaimed water forms a promising non-conventional water resource in Oman. When considering reclaimed water (RW) reuse for crop irrigation, an evaluation of the advantages, disadvantages and possible risks has to be made. The planners should consider piping reclaimed water (RW) to areas where groundwater of good quality is available to conjunctively use and meet crop water requirements (Alkhamisi et al., 2013). The level of impact depends on the degree of purification, the method and the location of reuse and develop in the form of pollution of the soil on the groundwater or on the surface water (Papadopoulos 1995; Kretschmer et al., 2002). The impact of RW on soil appears in the decrease of hydraulic conductivity because of high organic matter, blockage by suspended solids and growth of microorganisms. The movement of water in the soil depends on hydraulic gradients, soil permeability and infiltration rate. After 11 years of reclaimed wastewater irrigation, the availability of nutrients and nonessential elements, soil salinity and sodicity increased 2 to 3 times in comparison to soils irrigated with well water (Pereira et al., 2011). Adriel et al. (2005) found that the secondary-treated sewage effluent

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Table 1. Average values of EC (dS/m), pH, Nitrogen (mg/l), Cations and Anions for the three irrigation water types.

Parameter	Unit	Groundwater	Desalinized water	Reclaimed water
EC_w	dS/m	0.97	1.06	0.88
pH	-	7.8	7.5	7.7
Nitrogen N-NO_3^-(nitrate)	mg/l	14.31	0.463	28.70
Phosphorus P_3^-	mg/l	0.074	Nd	9.413
Potassium K^+	mg/l	3.626	17.83	22.93
Cations &Anions (mg/l)				
Sulfate SO_4^{2-}	mg/l	78.77	39.87	81.17
Bicarbonate HCO_3^-	mg/l	209.27	152.53	107.99
Carbonate CO_3^-	mg/l	Trace	Trace	Trace
Calcium Ca^{2+}	mg/l	15.43	38.91	58.21
Magnesium Mg^{2+}	mg/l	41.21	30.01	20.29
Sodium Na^+	mg/l	109.90	140.07	94.07
Chloride Cl^-	mg/l	125.84	276.49	140.02
Zinc Zn^{2+}	mg/l	0.446	0.461	0.546
Copper Cu^+	mg/l	0.026	0.026	0.027
Manganese Mn^{2+}	mg/l	0.004	0.011	0.048
Nickel Ni	mg/l	0.042	0.04	0.019
Boron B	mg/l	0.279	1.269	0.799
Molybdenum Mo	mg/l	0.063	0.083	0.112
Silicon Si	mg/l	0.187	0.974	0.959
Vanadium V	mg/l	0.01	0.064	0.043
Cobalt Co^{2+}	mg/l	0.303	0.320	0.250
Lead $Pb4^+$	mg/l	Nd	Nd	Nd
Chromium Cr^{2+}	mg/l	0.022	Nd	Nd
Cadmium Cd^{2+}	mg/l	Nd	Nd	Nd
Copper Cu^+	mg/l	Nd	Nd	Nd
Barium Ba^{2+}	mg/l	0.048	0.069	0.072
Sulfide S^{-2}	mg/l	Nd	5.581	22.97
Aluminum Al^{+3}	mg/l	0.088	0.096	0.093

Nd= not detected

application caused an increase in the soil total nitrogen, but did not change the total carbon and available P concentrations. Mohammad and Mazahareh (2003) found that the RW irrigation decreased soil pH and increased soil salinity, soil phosphorus (P), potassium (K) levels and the soil fertility improved. Soil salinity was reduced in the upper root zone (15 cm) through the continuous irrigation as the salts moved to the lower layer (30 cm) (Abdelrahman et al. 2011). RW can be a form of fertilizer since it has an important contribution of N, P and organic matter and can save farmers money on fertilizer.

Usually, RW is more saline than tap water, and therefore, when reused in irrigation can create salinity problems (Beltrao et al., 2003). RW applications reduced soil porosity, translation of pore size distribution towards narrower pores and as a result lead to a decrease in permeability (Rosa et al., 2007). After two years, soils irrigated with RW showed slightly significant changes in the physical and chemical properties such as pH, Electric Conductivity, SOC, Nitrogen, ESP, Sodium Adsorption Ratio and hydraulic conductivity K_{sat} (Zema et al., 2012).

Percolation of RW through the soil profile can reduce its saturated hydraulic conductivity (K_{sat}) depending on the RW quality, soil chemical properties and the pore size distribution in the soil (Lado and Ben-Hur, 2009). Levy et al. (2005) demonstrated that hydraulic conductivity of medium- and fine- textured soils was lower than 2 cm/h for nonsodic soils, however in the loamy sand rate of wetting had no effect on the K_{sat}. Tarchitzky et al. (1999) reported that the hydraulic conductivity K_{sat} decrease to 20% of its initial value after using reclaimed water. Irrigation with RW has adverse effects on soil health and environment and this is also due to increased pH and salinity. Application of RW increased soil salinity, organic matter, and decreased soil pH (Khan et al., 2012). Singh et al. (2009) concluded that RW irrigation modified the physicochemical properties of the soil. RW irrigation affected soils through increased organic matter, electrical conductivity and concentration of N, K, and P compared to the control treatment (Saffari and Mahboub, 2012). Kayikcioglu (2012) observed a decrease in N and microbial activities due to the lack of C availability in RW. However, no effect was observed on soil organic carbon content due to low content. Based on these recommendation of transferring the reclaimed water to agricultural area in Oman, this study was carried out with the objective to assess the impact of RW irrigation on soil properties such as salinity, hydraulic conductivity, cation exchange capacity and macro-nutrients considering time of harvest and soil depth.

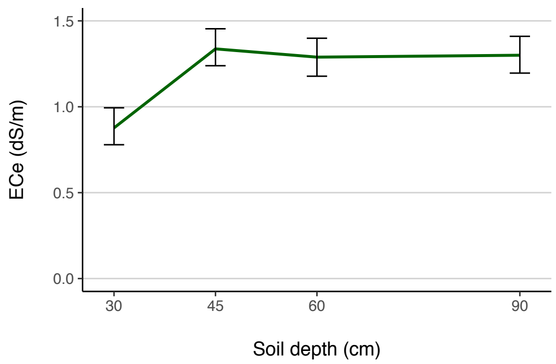

Figure 1. Wet weight (g/m2) of macro-fouling communities developed on acrylic, fiberglass, wooden and aluminum plates exposed for 4 months horizontally at the depth of 1m in Marina Shangri La. Data are means + 1 standard deviation. Means that are significantly different according to a HSD test (ANOVA: $p< 0.05$) are indicated by different letters above the bars.

Material and methods

Experimental design and soil sampling

Field experiments were laid out in a Completely Randomized Block Design (RCBD) with three replicates (Blocks) on 9 plots of 2.5 m width and 3 m length. The three different water sources, groundwater (GW), desalinized water (DW), and reclaimed water (RW), were used as treatment. Wheat (Triticum aestivum L.) was used in the first period of the experiment (mid-November to mid-March), cowpea (Vigna unguiculata L.) in the second period (April to mid-July) and maize (Zea mays L.) crop was in the third period (August to November). Six soil samples were taken from the experimental site prior the experiment layout at a depth of 30 cm and subjected to chemical and physical analysis. After laying out the experiment, soil samples were taken from each treatment location (reclaimed water, desalinized water and groundwater treatments) at four depths (0-30, 30-45, 45-60 and 60-90 cm) and subjected to chemical analysis. The analyses included soil salinity (EC_e), soil pH, carbon contents (Organic and Inorganic Carbon) and macro-elements (N, P and K).

Irrigation Water Application and Treatments

The irrigation system was operated to run under a pressure of 1 bar before planting. The application of the 3 water types was adjusted according to the reference evapotranspiration-ET_0. Daily reference evapotranspiration (ET_0) was calculated using Penman-Monteith equation (Allen et. al., 1998). The water applications were altered during the different stages of the crop growth (initial, development and late stages) according to each crop coefficient. Irrigation water was applied at 3 days intervals to compensate for evapotranspiration (ET_c) losses. ET_c was calculated using equation (1):

$$ET_c = K_c * ET_0 \quad (1)$$

where K_c is the crop coefficient for that stage and ET_0, the reference evapotranspiration.

Table 2. Textural composition of the studied soil.

Sample no.	Clay(%)	Silt(%)	Coarse sand (%)	Fine sand (%)	Soil type	Bulk density (g/cm3)	Particle density (g/cm3)	Porosity
1	7.46	1.88	38.98	51.68	Sandy	1.59	2.61	0.39
2	7.52	1.82	19.84	70.82	Sandy	1.38	2.40	0.43
3	5.52	1.82	29.84	62.82	Sandy	1.49	2.37	0.37
4	11.46	5.76	15.64	67.14	Loamy sand	1.43	2.35	0.39
5	7.46	3.76	22.46	66.32	Loamy sand	1.52	2.56	0.41
6	5.46	1.88	27.52	65.14	Sandy	1.57	2.46	0.36
Average	7.48	2.82	25.71	63.99	Loamy sand	1.49	2.46	0.39

Table 3. Soil electric conductivity (ECe), pH, hydraulic conductivity (K_{sat}), cation exchange capacity (CEC), total carbon (TC%), inorganic carbon (IC%), organic carbon (OC%), N, P and K contents for the three water types treatments before planting at depth 30 cm.

Parameter	Water irrigation treatments			
	Groundwater	Desalinized water	Reclaimed water	Mean
ECe (dS/m)	1.77	1.88	2.21	1.95
pH	7.07	7.17	7.20	7.14
K_{sat}(cm/s)	0.0327	0.0307	0.0187	0.0274
CEC(cmol/kg)	3.92	3.63	3.99	3.85
Total Carbon (%)	6.09	6.02	5.52	5.88
Inorganic Carbon (%)	3.81	4.01	3.76	3.86
Organic Carbon %	2.29	2.01	1.75	2.02
Nitrogen (%)	0.33	0.32	0.33	0.33
P (mg/kg)	23.23	25.70	29.17	26.03
K (mg/kg)	60.00	90.00	70.00	73.33

The reference evapotranspiration (ET_0) was expressed and then transformed to volume (cubic meter) through multiplying by the area of the plot. The amount of irrigation water applied at the first period (Wheat) was 451 mm GW, 465 mm DW and 464 mm RW. However, in the second period (Cowpea) it was 1523 GW, 1551 mm DW and 1536 mm RW. In the third period (Maize), it was 1054 mm GW, 1048 mm DW and 1043 mm RW for the total irrigation period.

Measurement of soil EC_e & pH

The saturated paste method was used to measure the soil salinity (EC_e) and pH. The soil solution EC was measured using EC/pH meter. The EC and pH meter were calibrated before use.

Measurement of hydraulic conductivity, K_{sat}

The hydraulic conductivity K_{sat} of a soil is a measure of the soil's ability to transmit water when subjected to a hydraulic gradient. Hydraulic conductivity is determined by Darcy's law, which is for one-dimensional vertical flow. This experiment was practiced to determine the hydraulic conductivity of a sandy loam soil by the constant head method. The methodology used for the experimental determination of K_{sat} in laboratory was based on procedures adapted from Bear (1972).

Measurement of CEC

The cation exchange capacity CEC was determined using the sodium acetate method (Rhoads, 1990). Sodium concentration in the supernatant liquid was determined using a Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES).

Table 4. Soil salinity, EC_e (dS/m) and pH irrigated with 3 different water types immediately after harvest of 3 different crops.

Treatments (water type)	Harvest timing			
	After wheat	After cowpea	After maize	Mean
Soil salinity				
Groundwater	2.058	0.863	0.439	1.120 b
Desalinized water	2.143	1.102	1.150	1.465 a
Reclaimed water	1.171	1.059	0.687	0.972 b
Mean	1.791 a	1.008 b	0.759 b	
Soil pH				
Groundwater	7.89	8.23	8.20	8.11 b
Desalinized water	7.89	8.20	8.18	8.09 b
Reclaimed water	8.06	8.26	8.26	8.19 a
Mean	7.95b	8.23a	8.21a	

*Means followed by similar letters are not significantly different.

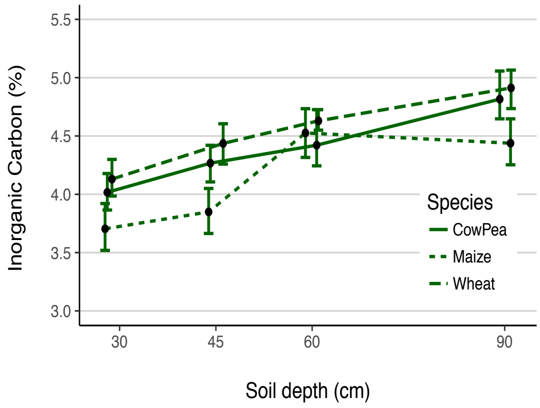

Figure 2. Soil inorganic carbon contents (%) at four soil depths after harvest of 3 different crops.

Measurement of total nitrogen, phosphorus and potassium

A Foss Tecator™ 2400 Kjeltec analyzer unit was used to determine nitrogen content in the soil samples following Kjeldahl's method. Samples of each treatment were analyzed for phosphorus (P) using Biochram™, Libra S22, spectrophotometer and potassium (K) was determined using Sherwood™, M410 Flame photometer (Sherwood, 2012).

Measurement of carbon content (organic and inorganic carbon)

Total carbon and inorganic carbon were determined using TOC analyzer TOC-V CPN from Shimadzu, Japan. Total Organic Carbon content was determined by difference between the total carbon content and the inorganic carbon contents (Total Carbon = Inorganic Carbon + Organic Carbon).

Table 5. Soil pH at four soil depths (30, 45, 60 and 90 cm) irrigated with 3 different water types.

Treatments (water type)	Soil depth 30 cm	45 cm	60 cm	90 cm
Groundwater	8.03	8.11	8.11	8.17
Desalinized water	7.99	8.10	8.11	8.17
Reclaimed water	8.15	8.14	8.29	8.19
Mean	8.06[bc]	8.11[ab]	8.17[a]	8.17[a]

*Means followed by similar letters are not significantly different

Statistical analysis

All data obtained from the effects of different irrigation water types treatments on soil physical and chemical contents were subjected to a statistical analysis using analysis of variance (ANOVA). The least significant difference (LSD) at α = 0.05 was performed to compare means using SPSS, Chicago, Ill.; and MstatC software, East Lansing, Mich. according to the methods of Gomez and Gomez (1984). Standard Errors (SE), represented by error bars, were used to compare series in the charts.

Results and discussion

Water and Soil Structure Analysis Prior to Planting

Quality of irrigation water

The analysis of irrigation water used in the various treatments (water types) is reported in Table 1. The salinity of irrigation water (EC_w) ranged from 0.97 dS/m (groundwater) to 1.06 dS/m (desalinized water). The pH values ranged from 7.5 for the DW to 7.8 for the GW. The total nitrogen values were 28.7, 14.31 and 0.463 mg/l in RW,

Table 6. Soil total carbon content (%) and organic carbon content (%) after harvest of 3 different crops at four soil depths.

Soil sample collection time (harvesting)	Soil depth (cm) 30-cm	45 cm	60 cm	90 cm	Mean
a) Total Carbon Content (%)					
After wheat	5.897	5.906	6.129	6.226	6.040[A]
After cowpea	5.619	5.505	6.715	6.722	6.140[A]
After maize	5.177	5.608	6.173	5.973	5.733[B]
Mean	5.564[b]	5.673[b]	6.339[a]	6.307[a]	
b) Organic Carbon Content (%)					
After wheat	1.766	1.488	1.522	1.358	1.534[B]
After cowpea	1.610	1.261	2.338	1.951	1.790[A]
After maize	1.476	1.768	1.672	1.564	1.620[B]
Mean	1.618[b]	1.505[b]	1.844[a]	1.625[b]	

*Means followed by similar letters are not significantly different.

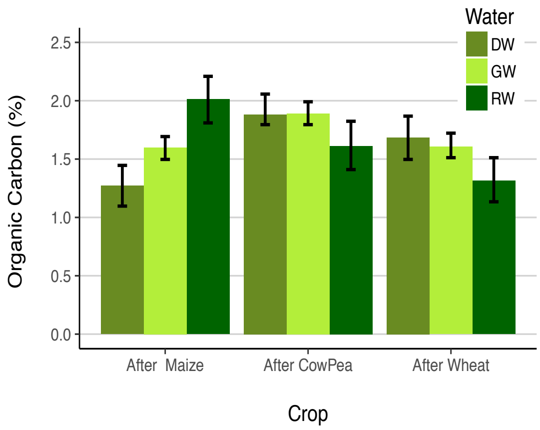

Figure 3. Soil organic carbon contents (%) with 3 different water types immediately after harvest of 3 different crops. DW = Desalinized water, GW = groundwater, RW = Reclaimed water.

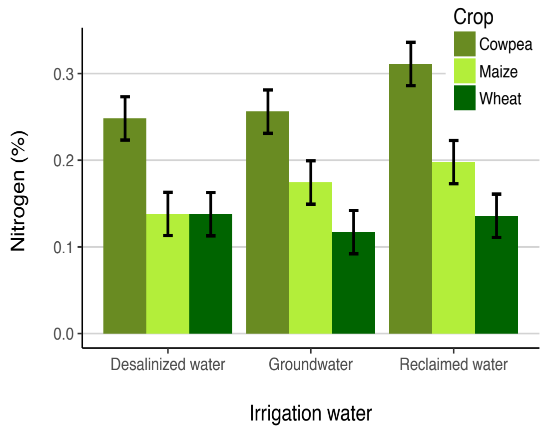

Figure 4. Soil total nitrogen (N%) with 3 different water types immediately after harvest of 3 different crops.

GW and DW, respectively. The RW was higher in SO4, K, Ca, Zn, Cu and Mn (Table 1). Values of other elements concentrations (mg/l) for the three irrigation water types are presented in Table 1. Lead (Pb), Cadmium (Cd) and Copper (Cu) were not detected in all types of irrigation water. Chromium was below detection levels in DW and RW whereas the GW contained 0.022 mg/l. The RW had higher concentration of Mo (0.112 mg/l), Ba (0.072 mg/l) and S (193.4 mg/l). However, Ni (0.042 mg/l) was the highest in groundwater. Desalinized water contains higher values of B (1.269 mg/l) V (0.064 mg/l), Co (0.320 mg/l) and Al (0.096 mg/l) in comparison to GW and RW.

Physical properties of the experimental soil

The soil physical constituents represented in clay, silt and sand %, and the bulk density, particle density and porosity of the experimental soil is presented in Table 2. The analysis of six random soil samples before planting indicated that the texture of the experimental soil ranged between sandy to loamy sand with a porosity of 0.36 to 0.43. Fine sand was the dominant constituent of the experimental soil structure (63.99%). The bulk density ranged between 1.38 to 1.59 g/cm^3 with an average of 1.49 g/cm^3 and the average particle density was 2.46 g/cm^3 (Table 3).

Chemical properties of the experimental soil before planting

The soil EC_e analysis of the three water types before planting are presented in Table 3. Soil EC_e before planting ranged between 1.77 to 2.21 dS/m. It was higher than that at harvesting of each crop. Generally, the analysis before planting showed a lower soil pH. The hydraulic conductivity (cm/s) and cation exchange capacity (cm mol/kg) of the experimental soil before planting are also presented in Table 3. The total carbon TC%, inorganic carbon IC%, organic carbon OC%, N, P and K contents in the plots of the water types treatments before planting are presented in Table 3.

Table 7. Soil organic and inorganic carbon content (%) irrigated with three water irrigation types after wheat, cowpea and maize harvest.

Water type	Harvest type	Inorganic carbon (%)	Organic carbon (%)
Groundwater irrigation	Wheat	4.533a	1.605b
	Cowpea	4.174b	1.889a
	Maize	4.008bc	1.596b
Desalinized water irrigation	Wheat	4.419a	1.680b
	Cowpea	4.406a	1.871a
	Maize	4.389a	1.262c
Reclaimed water irrigation	Wheat	4.566a	1.315c
	Cowpea	4.471a	1.610b
	Maize	3.941c	2.003a

*Means followed by similar letters in columns are not significantly different at α=0.05.

Table 8. Soil saturated hydraulic conductivity, K_{sat} (cm/s) irrigated with 3 different water types at four soil depths.

Treatments (water type)	Soil depth					Soil mean K_{sat} before planting
	30 cm	45 cm	60 cm	90 cm	Mean	
Groundwater	0.0156	0.0197	0.0439	0.0830	0.0406	0.0327
Desalinized water	0.0375	0.0183	0.0310	0.0869	0.0434	0.0307
Reclaimed water	0.0318	0.0241	0.0313	0.0930	0.0451	0.0187
Mean	0.0283 ^{c}	0.0207 ^{c}	0.0354 ^{b}	0.0877 ^{a}		0.0274

*Means followed by similar letters are not significantly different

Soil Analyses after Harvest

Effect of reclaimed water on soil salinity and pH

The analysis of variance for soil salinity (EC_e) showed significant differences ($p<0.05$) between the treatments, the timing and their interaction whereas there were no significant differences with respect to soil depth and its interactions with the treatments and harvest timing. Regarding the soil pH, there were significant differences ($p<0.05$) among the treatments, soil depth and the harvest timing. The interactions between the treatments, soil depth and the timing didn't show any significant differences. The means of the soil salinity (dS/m) for the water types (groundwater, desalinized water and reclaimed water) after each crop harvesting (after wheat, cowpea and maize crop harvest) are presented in Table 4. The soil irrigated with desalinized water showed the highest salinity (1.465 dS/m). This is likely due to higher salinity of the DW (1.06 dS/m) compared to GW (0.97 dS/m) and RW (0.88 dS/m) (Table 1). GW had a slightly higher salinity than reclaimed water (1.12 and 0.972 dS/m, respectively). Soil salinity decreased with the time: it started with 1.791 dS/m after wheat crop followed by the cowpea (1.008 dS/m) then after the maize crop (0.759 dS/m). The main factor governing the soil salinization is the irrigation procedures. Rate of irrigation during the summer season was enough to prevent the rise of salt from the deeper layers. Although there were no significant differences in soil salinity with soil depth, the upper layer (15 cm) had the lowest soil salinity for all three water types compared to the lower layers (Fig. 1). This is in agreement with Belaid's et al. (2010) findings that salinity decreases with harvest timing. Belaid et al. (2010) found that EC_e increased with soil depth (0.92, 1.87 and 2.07 dS/m in 0-30, 30-60 and 60-90 cm, respectively) in a fluvisol soil but decreased in a calcisol soil and pH increased with soil depths in both soil types under RW irrigation. Irrigation with RW was observed to slightly reduce the soil pH and did not markedly increase the soil salinity when compared to background values (Jun-feng et al., 2007). The means of soil pH for the water types after each crop is presented in Table 4 and fall within a narrow range. The soil pH was higher in the reclaimed water treatments (8.19). However, the desalinized water (8.09) and groundwater (8.11) were not significantly different. There was an increase in soil pH after each crop harvest: soil pH after wheat was 7.95 and increased to 8.23 and 8.21 after cowpea and maize crops, respectively. Soil pH also increased with soil depth until 60 and 90 cm (Table 5). Belaid et al. (2010) found an increase in soil pH after reclaimed water irrigation. The last two depths (60 and 90 cm) didn't show significant difference. No negative effects with respect to changes in soil pH or salinity occurred when using RW from the Albacete STP (Manas et al., 2012).

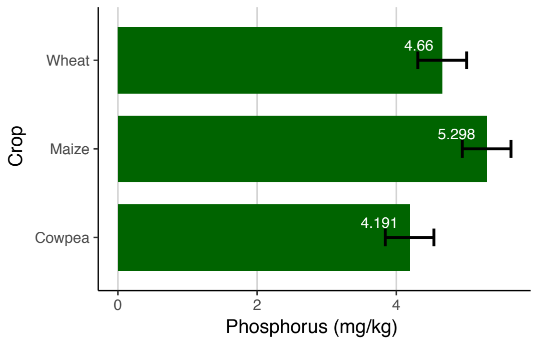

Figure 5. Phosphorus content (mg/kg) after the harvest of 3 different crops.

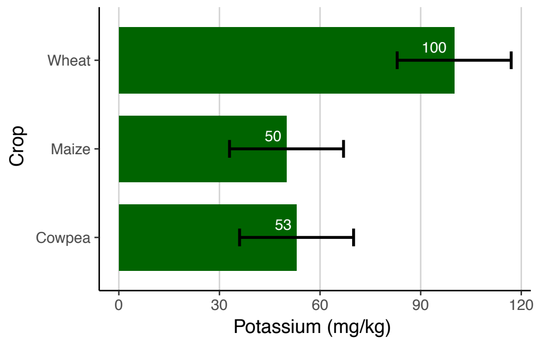

Figure 6. Potassium content (mg/kg) after the harvest of 3 different crops.

Table 9. Soil cation exchange capacity (CEC) (cm·mol/kg) irrigated with 3 different water types at four soil depths.

Soil depth (cm)	Water type			
	Groundwater	Desalinized water	Reclaimed water	Mean
30 cm	12.63	13.52	11.25	12.47c
45 cm	22.49	21.44	22.65	22.20b
60 cm	20.95	20.43	20.65	20.68b
90 cm	42.17	31.81	33.46	35.81a
Mean	24.56	21.80	22.00	
CEC before planting	3.92	3.63	3.99	

*Means followed by similar letters are not significantly different at α=0.05.

Effect of reclaimed water on soil organic and inorganic carbon

The analysis of variance did not show significant differences in carbon content (Total carbon, TC%; Organic Carbon, OC% and Inorganic Carbon, IC%) or between water types (groundwater, desalinized and reclaimed water). However, there were significant differences in TC and OC percentage ($p<0.05$) with soil depth and harvest timing treatments. With respect to IC%, there were no significant differences ($p>0.05$) among all treatment except for the interactions of the harvest timing with both water types and soil depth. The interaction of treatment × soil depth × harvest timing didn't show significant differences at α=0.05 with respect to all the three forms of carbon (TC, OC and IC %). The percentage soil total carbon contents during three different times of harvesting at four soil depths is presented in Table 6. The upper two depths (30 and 45 cm) were significantly different ($p<0.05$) from the lower depths (60 and 90 cm). The soil TC% was the highest at 60 cm (6.339 %) and 90 cm (6.307 %) depths followed by 45 cm (5.673 %) and 30 cm (5.564 %) depths. The soil TC% was higher after wheat and cowpea harvest in comparison to that after maize. It was 6.140 % after cowpea followed by 4.040 % after wheat and 5.733% after harvesting of maize.

The soil inorganic carbon (IC %) decreased with time of harvest in groundwater (-10%) and reclaimed water treatments (-14%) but it did not show difference with desalinized water irrigation (Fig. 3). The soil irrigated by RW after maize harvesting had the lowest IC content but the soil after wheat and cowpea had no significant difference in IC. The results suggest an increase of IC % in soil with the increase of soil depth after each harvesting time (Fig. 2). The increase was 7, 12, and 18% with respect to 45, 60 and 90 cm, respectively after wheat harvesting. It was 6, 9, and 19% after cowpea harvesting at the same depth. After maize harvesting, the increase was 4, 22, and 19%, respectively (Fig 2). The organic carbon did not show significant difference ($p<0.05$) after wheat and cowpea harvest and increased over time in the soil irrigated with reclaimed water (Fig 3). Organic carbon also increased in the soil that was irrigated with groundwater and desalinized water.

Soil organic and inorganic carbon contents with three water irrigation types after wheat, cowpea and maize harvest are presented in Table 7. Soil organic carbon contents % during three different times of harvesting at four soil depths is illustrated in Table 7. Organic carbon percentage at soil depth 60 cm was the highest followed by that of 90, 30 and 45 cm. The OC% (1.97%) was higher after cowpea harvest than that after the wheat and maize harvest (1.534 and 1.620%, respectively) (Table 6). The soil organic carbon was higher before planting. Percentage of organic carbon seems to increase with time in reclaimed water irrigation after maize and cowpea harvesting. Jueschki et al. (2008) found that OC accumulate in the topsoil but decrease after long-term irrigation with secondary RW. Organic carbon was found to be higher after cowpea harvest compared to that after wheat and maize harvest. Kone et al. (2008) studied the impact of farming system on soil status using legumes crops and reported that soil organic carbon increased over time under all legume based systems.

Effect of reclaimed water on saturated hydraulic conductivity, K_{sat}

The statistical analysis didn't show significant difference at $p<0.05$ between water types and the interaction between water types and soil depths in respect to soil saturated hydraulic conductivity, K_{sat}. However, K_{sat}(cm/s) increased with soil depths (Table 8). The highest saturated hydraulic conductivity was at 90 cm (315.7 cm) followed by that of 60 cm (127.4 cm). The soil depths of 30 and 45 cm had the lowest saturated hydraulic conductiv-

Table 10. Total soil nitrogen (%) after harvest of 3 different crops at four soil depths.

Soil depth (cm)	Nitrogen (%)		
	Wheat	Cowpea	Maize
30	0.0254 b	0.0238 b	0.0155 d
45	0.0157 cd	0.0354 a	0.0146 d
60	0.0058 e	0.0322 a	0.0170 cd
90	0.0055 e	0.0180 cd	0.0216 bc

*Means followed by similar letters are not significantly different at α=0.05.

Table 11. Phosphorus and potassium content (mg/kg) with 3 different water types at four soil depths.

Soil depth (cm)		Treatments (water type)		
	Groundwater	Desalinized water	Reclaimed water	Mean
Phosphorus (mg/kg)				
30 cm	5.25	6.03	4.75	5.34 [a]
45 cm	4.37	4.71	5.18	4.76 [b]
60 cm	4.05	5.33	4.49	4.62 [bc]
90 cm	3.82	4.40	4.23	4.15 [c]
Mean	4.38	5.12	4.66	
Potassium (mg/kg)				
30 cm	87.78	73.33	74.44	78.52 [a]
45 cm	85.56	78.89	78.89	81.11 [a]
60 cm	66.67	62.22	61.11	63.33 [b]
90 cm	57.78	48.89	50.00	52.23 [c]
Mean	74.44	65.83	66.11	

*Means followed by similar letters are not significantly different at α=0.05.

ity (101.8 and 74.5 cm, respectively). Lado and Ben-Hur (2009) stated that K_{sat} of a sandy soil was not affected because of its large pore size. The hydraulic conductivity was not affected by irrigation of all types of water (RW, GW and DW). In a 15-year study, irrigation with effluent decreased the steady-state K_{sat} from 82 to 29 cm/h in the topsoil samples, and from 93 to 35.5 cm/h in the subsoil samples (Gharaibeh et al., 2007). This decrease could have resulted from changes in chemical properties of the soil caused by long-term irrigation with secondary RW. Our study, on the other hand, was for one year only and used tertiary treated wastewater in sandy to sandy loam soil resulting in limited change in soil conductivity.

Effect of reclaimed water on soil cation exchange capacity (CEC)

The soil cation exchange capacity (cmol·kg^{-1}) is presented in Table 10. There was a significant difference at p<0.05 between soil depths but no significant differences (p<0.05) were found between the water type nor with its interaction with soil depth. The CEC increased with soil depths. The highest value of CEC was at 90 cm (35.81 cmol·kg^{-1}) followed by depths 45 and 60 cm (22.20 and 20.68 cmol·kg^{-1}, respectively). The minimum CEC was 12.47 cmol·kg^{-1} in the top soil depth 30 cm (Table 9). Kiziloglu (2008) found an increase in soil CEC which ranged from 32.1 to 39.2 cmol·kg^{-1} in a soil irrigated with TWW. Rusan et al. (2007) found CEC to be 32.1 cmol·kg^{-1} after 2 years of TWW irrigation. In Hong Kong, Jim (1998) found that CEC decreased with soil depth, despite observing low values (10.72, 7.43, 7.05 and 2.21 cmol·kg^{-1} at depths 0 to 10, 10 to 33, 33 to 53 and 53 to 66 cm, respectively). He reasoned that this decrease was due to the lack of inorganic colloids which did not provide enough exchangeable sites for nutrient adsorption.

Effect of reclaimed water on total nitrogen, phosphorus and potassium

The analysis of variance quantifying the effect of water type, soil depth and harvesting on soil total nitrogen concentration revealed significant differences (p<0.05) between harvest and its interaction with the soil depth. However, no significant differences (p<0.05) were observed with respect to the water types nor with their interaction with depth and harvest. All the interactions (Water type × Soil depth, Water type × Harvest timing, Soil depth × Harvest timing and Water type × Soil depth × Harvest timing) were non-significant with respect to phosphorus and potassium contents. The soil total nitrogen was highest after cowpea harvest in all types of irrigation types (Fig. 4). This is likely due the nature of cowpea as a leguminous crop that has high nitrogen fixation potential compared to wheat and maize crops. The nitrogen content before planting was highest (0.32-0.77%). The highest N concentration appeared after cowpea harvesting at the soil depths 45 and 60 cm (0.0354 and 0.0322, respectively). The lowest was after wheat harvest at the deepest layers of 60 and 90 cm (0.0058 and 0.0055%, respectively) and then it increased after cowpea harvest. The nitrogen content was 0.0172% after the maize harvest which did not significantly differed from that after wheat (0.013 %). The cowpea increased N % to 0.027 % (Fig. 4).

Total soil nitrogen (N%) after the different harvest at four soil depths is presented in table 10. The maximum total nitrogen was found in the soil samples after cowpea at soil depth 45 and 60 cm (0.0354 and 0.0322 %, respectively) followed by that after wheat at depth 30 cm (0.0254 %) which did not significantly differ from the soil after cowpea at 30 cm (0.0238 %) and after maize at 90 cm (0.0216 %). The lowest N found in the soil after maize at depths 30 and 45 cm (0.0155 and 0.0146 %, respectively). Generally, the total N was found to be higher in the top soil (30-45 cm) compared to lower (60-90 cm) after wheat and cowpea. This is in agreement with Rusan et al. (2007) after barley grown for two years in Jordan. However, the soil after maize was not consistently affected.

Phosphorus concentration in the soil did not vary significantly with irrigation water types. However, the difference was significant between soil depths. The upper layers (30 and 45 cm) contain higher phosphorus compared to the lower layers (60 and 90 cm). The soil at 30 cm was the highest (5.34 mg/kg) in P, whereas, the depth 45 cm (4.76 mg/kg) was not significantly different from 60 cm soil depth (Table 11). The lowest value of phosphorus was at soil depth 90 cm (4.15 mg/kg). Also, P fertilizer applied to the soil is not highly mobile by water irrigation using drip irrigation system. Generally, phosphorus content will decrease with depth with all water types (Rusan et al., 2007). The average phosphorus in the experimental soil (26.03 mg/kg) was higher before planting (Table 3). This could be because phosphorus has slower movement due to its adsorption by soil. Concerning the harvest timing, it is found that the soil after maize (5.30 mg/kg) had the highest P concentration compared to that after wheat and cowpea harvest (4.66 and 4.20 mg/kg, respectively) (Fig. 5). RW supplied the essential macro nutrients (P and N) and enhanced the C and N turnover in the soil after 15-years irrigation (Belaid et al., 2012).

Soil potassium content (mg/kg) for the three water type irrigation treatments at four soil depths is presented in Table 11. The potassium at 30 cm (78.52 mg/kg) did not significantly differ from that at depth 45 cm, though it was higher at the lower depth (81.11 mg/kg). Although there was no significant difference between water types, the soil irrigated with groundwater showed elevated potassium concentration in all soil depths. Potassium decreased with depths of 60 and 90 cm (63.33 and 52.23 mg/kg, respectively). Mohammad and Mazahreh (2003) reported potassium at soil depth 30 cm to be 581 mg/kg and 638 mg/kg at 60 cm after secondary RW irrigation. That could be due to the fact that potassium exists in the soil as a mineral and the transfer of mineral potassium to other states is a very slow process which causes it to be lower in deeper soil layers and not available for plant uptake during a single growing season. However, the results in figure 6 showing that the potassium decreased to about 50% in the three seasons, from 100 mg/kg after wheat harvesting to about 54 and 53 mg/kg after cowpea and maize, respectively. The movement of K from topsoil and through the soil profile varies with soil texture (Schjoning et al., 2004).

Conclusion

Salinity of soils irrigated by reclaimed water was lower compared to those irrigated with desalinized water or groundwater. The soil organic carbon was found to be the highest after maize harvest under RW irrigation. RW irrigation did not alter soil hydraulic conductivity or cation exchange capacity but increased the nitrogen in the soil compared to DW and GW and enhanced further after cultivation. The RW did not affect neither soil phosphorus nor potassium. Generally, reclaimed water can be used as a source of water irrigation in Oman without any adverse effect to soil with respect to hydraulic conductivity, cation exchange capacity, organic carbon and the macro-nutrients (Nitrogen, Phosphorus, and Potassium).

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