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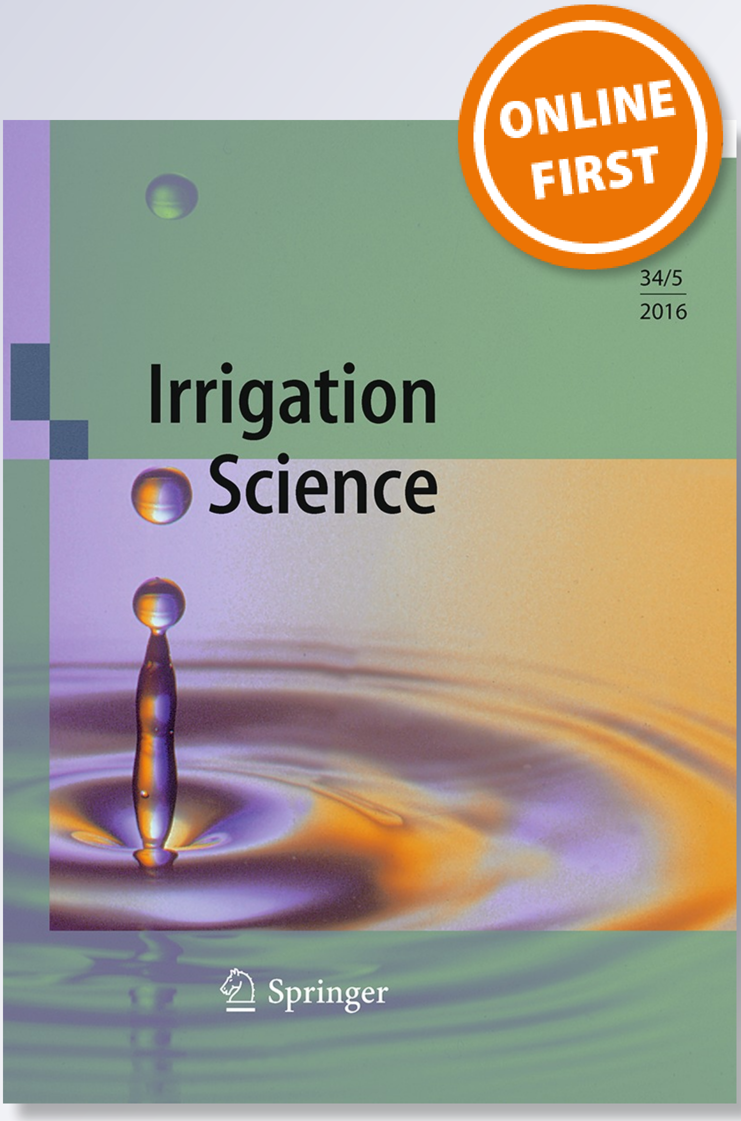

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ORIGINAL PAPER

Effect of reclaimed water irrigation on yield attributes and chemical composition of wheat (*Triticum aestivum*), cowpea (*Vigna sinensis*), and maize (*Zea mays*) in rotation

Saif A. Alkhamisi[1] · M. Ahmed[2] · M. Al‑Wardy[2] · S. A. Prathapar[3] · B. S. Choudri[4]

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Abstract Irrigating crops with reclaimed water from sewage treatment plants can contribute to the conservation and augmentation of the water resources in arid regions. Many countries in the Middle East, North Africa and Sub-Saharan Africa are suffering from serious water shortages. Three field studies were conducted during the period 2010–2011 to assess yield components and chemical constituents of wheat, cowpea and maize crops grown in rotation with reclaimed water for irrigation in comparison with desalinated and groundwater. The reclaimed water irrigation increased wheat plant height (cm), chlorophyll, leaf area (cm^2), leaf length (cm), grain yield ($t\ ha^{-1}$) and the water productivity ($kg\ grain\ m^{-3}$). It improved all cowpea growth parameters under study except the dry forage yield. Nitrogen was also higher under reclaimed water irrigation in wheat tissue, cowpea pods and maize cobs. Reclaimed water had no effect on the element concentrations in wheat, cowpea and maize except for nickel concentration in wheat plants, and Sodium and Manganese concentrations in maize plants. Using reclaimed water for irrigation increased the yield parameters of wheat, cowpea and maize. However, all the studied element concentrations in wheat, cowpea and maize were within the normal limits after irrigation by reclaimed water. It can be concluded that reclaimed water usage will have significant positive impacts on yield and water productivity.

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✉ B. S. Choudri
bchoudri@squ.edu.om

1 Ministry of Agriculture and Fisheries, Muscat, Sultanate of Oman

2 College of Agricultural and Marine Sciences, Sultan Qaboos University, Muscat, Sultanate of Oman

3 Department of Primary Industries, Queanbeyan NSW, Sydney, Australia

4 Center for Environmental Studies and Research (CESAR), Sultan Qaboos University, Muscat, Sultanate of Oman

Introduction

Water is considered the most limited natural resource in arid regions. The governments, to combat the water shortage problem, have adopted water resources augmentation together with conservation. Reclaimed Water (RW) is an important source of nonconventional water resource, which is currently used for irrigation. Reclaimed water (often termed as treated wastewater) reuse is an essential part of the water demand management in many water stressed countries. Adewumi et al. (2010) concluded that significant potential exists for implementing wastewater reuse for large nondrinking application in arid areas of South Africa, especially Western Cape Province. Different studies showed an increase of both the quantity and the quality of crops irrigated with reclaimed water. Al-Lahham et al. (2003) found that the secondary reclaimed water could be used as an alternative for irrigation of tomatoes eaten after cooking. The tomato fruit size and weight increased with the increase volume of reclaimed water used. Al-Nakshabandi et al. (1997) found that eggplant yield under reclaimed water was twice the average eggplant production under fresh water irrigation using conventional fertilizer application. Reclaimed water can be used with success to irrigate crops. High yields can be obtained even if very limited chemical fertilizer is applied to crops, since the reclaimed water itself contains nutrients (Karajeh et al. 2000). Al-Ajmi et al. (2009) found that tertiary reclaimed water is a feasible source for irrigation of hydroponically produced barley crop. Barley plants utilized 30 % more water when irrigated with RW than with tap water, while dry matter production with reclaimed water was higher by over 20 %. Reclaimed water irrigations increased yields of forage maize and their water productivity (Alkhamisi et al. 2011; Alkhamisi 2013). No influence of reclaimed water when compared against fresh water on corn yield and irrigation water productivity (IWP) which found to be 2.12 kg m^{-3} was noticed (Hassanli et al. 2009). The use of reclaimed water in irrigation did not show any significant effect on the elemental chemical composition of forage maize plants except for N, which appeared to be greater in plants, irrigated with the RW (Abdelrahman et al. 2011). In term of elements concentrations in crops, an increase was observed in N, P, K, Zn, Cu, Zn and Mn concentrations in grain and frond of beans in Iran under reclaimed water irrigation as compared to the fresh water but that concentrations were lower than the toxic threshold (Saffari and Mahboub 2012). The biomass yield of *Typha latifolia* was increased by irrigation with RW, while *Arundo donax* showed the greatest capacity to survive after transplanting (Zema et al. 2012). Cauliflower with relatively lower transfer factor for Cd, Pb, As and Cr was suitable for cultivating under reclaimed water in Beijing–Tianjin city (Wang et al. 2012). Khan et al. (2012) found that reclaimed water reduced canola vegetative and reproductive growth. No effect on element concentration was observed in barley, sorghum and maize when irrigated with reclaimed water except for N and B (Ali et al. 2011). Heavy metals uptake by alfalfa was much higher under reclaimed water irrigation (Basahi et al. 2007) but below toxicity level because the concentrations were less than phytotoxic level (Mohammad et al. 2011). The micronutrients and toxic elements in alfalfa stem and leaves gradually decreased as reclaimed water in the mixed irrigation water decreased (Basahi et al. 2007). The levels of heavy metals Hg, Cu, Zn, Cd, Pb, Ni and Cr in grains, wheat and rapeseed were much lower than the safe recommended values due to their low concentrations in reclaimed water (Jun-feng et al. 2007). Kiziloglu et al. (2008) found that reclaimed water increased the cabbage and cauliflower yields as well as the concentration of N, P, K, Ca, Mg, Na, Fe, Mn, Zn, Cu, Pb, Ni and Cd. Therefore, studies are necessary to ensure effective and safe implementation of reclaimed water reuse, as this will increase confidence in reclaimed water as a valuable resource. Long-term effects of irrigation with reclaimed water have been looked into by various researchers (Al-Omron et al. 2012; Mapanda et al. 2005; Rattan et al. 2001; Yadar et al. 2002; Rusan et al. 2007). Al-Omron et al. (2012) reported in a case study from Saudi Arabia that after 13 years of continuous irrigation with reclaimed water, there was slight increase in soil salinity, organic matter increased substantially and most importantly, heavy metals such as Zn, Pb, Fe, Ni, Mn, Cu, Cr, Co and As increased significantly compared to well water-irrigated soil samples. Mapanda et al. (2005) predicted, based on a study in Zimbabwe, that all studied heavy metals would have exceeded the permissible limits in 5–6 years of continuous irrigation with reclaimed water. This study was conducted to assess the performance of wheat, cowpea and maize crops grown in rotation throughout the year in the Sultanate of Oman and monitor the yield and chemical characteristics of wheat, cowpea and maize crops under reclaimed water irrigation.

Materials and method

Study area

A study consisting of three field experiments was conducted during the period from November 15, 2010 to November 14, 2011 comprising the whole year at the Agricultural Research Center (ARC), Rumais, Sultanate of Oman, (23° 42′ 33″ N, 57° 53′ 12″ E). ARC is located in a well-populated coastal plain with extensive agricultural activity called Al-Batinah South Governorate. This area has an arid climate, with less than 100 mm annual rainfall and summer temperatures often exceeding 40 °C (Choudri et al. 2013, 2015). However, because of the low elevation and close proximity to ocean, the humidity can reach up to 90 %. The soil of the experimental field is sandy loam texture with a porosity of 0.36–0.43. Fine sand was the dominant constituent of the experimental soil structure (63.99 %). However, the bulk density ranged between 1.38 and 1.59 g cm^{-3} with an average of 1.49 g cm^{-3}. The average particle density was found to be 2.46 g cm^{-3}.

Experimental design

The field experiments were laid out in a randomized completely block design (RCBD). With six replications (Blocks) on 18 plots of 2.5 m width and 3 m length, the plot size was 7.5 m^2 with 2 m space between one plot and the other. The three water irrigation types were used as treatments, namely groundwater (GW), desalinated water (DW) sourced from the sea and reclaimed water (RW) sourced from a treatment plant which uses domestic wastewater. Wheat was used in the first period experiment; cowpea was in the second period, and maize crop was in the third period.

Water quality analysis

Water quality was analyzed for all the three types of water used in the experiment according to the Standard Method for the Examination of Water (AOAC 1994) in respect of parameters

Table 1 Amount of irrigation water applied in mm at each crop period

Water type	Amount of irrigation water applied					
	1st period (wheat)		2nd period (cowpea)		3rd period (maize)	
	(m^3)	(mm)	(m^3)	(mm)	(m^3)	(mm)
Groundwater	20.295	451	68.535	1523	47.430	1054
Desalinated water	20.925	465	69.795	1551	47.160	1048
Reclaimed water	20.880	464	69.120	1536	46.935	1043

viz. salinity of irrigation water (ECw), potential of hydrogen (pH), nitrogen, sulfur, potassium, calcium and heavy metals such as zinc (Zn), copper (Cu), manganese (Mn), molybdenum (Mo), lead (Pb), chromium (Cr), barium (Ba), nickel (Ni), boron (B), vanadium (V), cobalt (Co) and aluminum (Al).

Irrigation water application and treatments

In this study, plots were irrigated with three different water sources: groundwater (GW), desalinated water (DW) and tertiary reclaimed water (RW) brought from Al-Manumah Sewage Treatment Plant (9 km from ARC). The irrigation system was operated to run under a pressure of 1 bar to determine the discharge rate and distribution efficiency of the drippers. Catch cans were used to collect the water from each plot, and the volume of the water in each can was measured using a graduated cylinder to calculate the discharge of the dripper per minute. The uniformity or distribution efficiency for the drip irrigation system in the experimental area was calculated to be 94 %. The three water types were administered according to the reference evapotranspiration—ETo—that was calculated using Penman–Monteith equation (Allen et al. 1998). ETo was calculated using average of 2 years (2010–2011) climatic data which was obtained from Seeb airport climatological data. Water applications were altered during the different stages of the crop growth (i.e., initial, development and late stages) according to each crop coefficient. Irrigation water was administered every 3 days. Irrigation water was applied to compensate for what was lost by evapotranspiration (ETc) during the previous 3 days. ETc was calculated using Eq. (1):

$$\mathrm{ETc} = \mathrm{Kc} * \mathrm{ETo} \quad (1)$$

Kc is the crop coefficient during different growth stages of the selected crops (wheat, cowpea and maize) (Food and Agriculture Organization 1998). It represents the relationship between ETo and ETc. The crop evapotranspiration (ETc) was expressed in terms of depth (mm) and then converted to volume (cubic meter) through multiplying by the area of the plot. The irrigation system used was drip irrigation. The amount of water applied for each treatment was determined using water meters (Table 1). The irrigation water samples were collected frequently and analyzed for salinity (ECw), pH and cations and anions concentrations.

Planting and fertilization

The crops, wheat (*Triticum aestivum*), cowpea (*Vigna sinensis*) and maize (*Zea Mays*), were planted on November 14, 2010, March 14, 2011 and August 9, 2011, respectively. The harvesting dates were March 2, 2011; June 22, 2011 and November 15, 2011 for wheat, cowpea and maize, respectively. Wheat and cowpea crops were planted in drills with a spacing of 0.25 m between lines, whereas maize was planted in 0.5 m line spacing and 0.25 m between plants. Two meters gap was left between adjacent plots.

The fertilizers were applied equally in all treatments as per recommendation of Akhtar and Nadaf (2002). A quantity of 120 kg P_2O_5 (240 kg triple super phosphate) and K_2O/ha (250 kg potassium sulfate/ha) was added for maize. Nitrogen requirement for maize was estimated to be 225/ha. The fertilizers were applied manually at 8–10 cm distance from the plants. The wheat crop was fertilized with 150 kg N/ha, 90 kg P_2O_5/ha and 60 kg K_2O/ha in the form of urea (300 kg/ha), triple super phosphate (180 kg/ha) and potassium sulfate (120 kg/ha), respectively. An application of 100 kg P_2O_5/ha (200 kg triple phosphate/ha) and 50 kg K_2O/ha, (100 kg potassium sulfate/ha) was recommended for cowpeas. It was split into 1/3 of the dose at planting and 2/3 of the dose after 1 month for the date of first application.

Crop harvesting and sampling

The harvesting was done at maturity stage of each crop. The crops were harvested for both tissues and grains. Samples from each crop irrigated by reclaimed water (RW), groundwater (GW) and desalinated water (DW) treatments in each plot were collected. The samples were dried and subjected to chemical analysis. Samples of 2–4 plants were weighed after drying in oven at a temperature of 70 °C for 72 h (3 days).

Yield and yield attributes

Yield and yield attributes for each crop were recorded 1 day before harvesting. The plant height (cm) and the green and dry yield (t ha^{-1}) of the three crops for both biomass and grains were collected and recorded. Other agronomic characteristics like number of leaves per plant, leaf length and leaf area were also taken during maturity stages of plant growth. Leaf chlorophyll content was evaluated when plants were in the late stage by using a portable chlorophyll meter (Minolta-SPAD-502 Model). Five readings of the seventh leaf of each crop from the tagged plants per experimental unit (plot) were taken. The values measured by the Chlorophyll Meter SPAD-502 corresponded to the amount of chlorophyll present in the plant leaf. These values were calculated based on the amount of light transmitted by the leaf in two wavelength regions in which the absorbance of chlorophyll is different. Leaf area was measured using a leaf area meter type CI-202. In addition, leaf lengths of the same plants for wheat and maize were measured using a ruler.

Water productivity

The water productivity is the ratio of yield obtained per unit of water used by the crop. The water productivity (WP) was calculated using Eq. (2):

$$\mathrm{WP} = \frac{\text{Yield per unit area (kg)}}{\text{Water used to produce that yield } (\mathrm{m}^3)} \quad (2)$$

Chemical analysis of plants

Plant samples (2–4 plants) were collected from each plot at harvest stage for the tissue and grains. Leaves for each crop were washed with distilled water and dried in oven at 70 °C for 72 h. They were ground and digested in 40 ml diamine pentaacetic acid (DPTA) solution. Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES) did determination of micro-elements and the trace elements for plant and soil samples.

Statistical analysis

All data obtained from the effects of different irrigation water types treatments on plants yields and chemical contents were subjected to a statistical analysis using analysis of variance (ANOVA). The least significant difference (LSD) at probability of 5 % ($p < 0.05$) was performed to compare means using SPSS for windows (Release 10.0.1) and MstatC software (Version 1.41) according to the methods of Gomez and Gomez (1984).

Results and discussion

Water analysis

The analysis of the soil and irrigation water used for the various treatments (water types) is reported in Tables 2 and 3. The salinity of irrigation water (ECw) ranged between 0.97 dS/m (GW) to 1.06 dS/m (DW). 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^{-1} in RW, GW and DW, respectively. The RW was higher in SO_4, K, Ca, Zn, Cu and Mn (Table 3). Lead (Pb), cadmium (Cd) and copper (Cu) were not detected in all types of irrigation water. Chromium was not detected in DW and RW, whereas the GW contained 0.022 mg l^{-1}. The RW had higher concentration of Mo (0.112 mg l^{-1}), Ba (0.072 mg l^{-1}) and S (193.4 mg l^{-1}). However, Ni (0.042 mg l^{-1}) was the highest in groundwater (GW). Desalinated water (DW) contained higher values of B (1.269 mg l^{-1}) V (0.064 mg l^{-1}), Co (0.320 mg l^{-1}) and Al (0.096 mg l^{-1}) in comparison with GW and RW.

Table 2 Analysis of soil (saturation paste extract) quality before planting

Water quality parameters	Water irrigation type		
	Groundwater	Desalinated water	Reclaimed water
ECe (dS m^{-1})	1.77	1.88	2.21
pH	7.07	7.17	7.2
N (%)	0.33	0.32	0.33
Elements (mg kg^{-1})			
P	23.23	25.7	29.17
K	60	90	70
Na	25.48	28.10	28.20
Mg	58.56	61.58	59.60
Ca	372.89	376.86	378.30
Zn	0.205	0.227	0.25
S	9.173	8.56	11.164
Fe	1.738	1.637	1.867
Mn	1.274	1.24	1.408
Co	0.02	0.024	0.033
Cu	0.075	0.109	0.076
B	0.971	1.04	1.086
Pb	0.366	0.293	0.32
Ba	0.114	0.121	0.116
Si	0.889	0.861	0.930

Effect of reclaimed water irrigation on wheat crop

The results of statistical analysis showed significant differences ($p < 0.05$) for the water types with respect to plant height (cm), chlorophyll, leaf area (cm^2) and leaf length (cm). The plants irrigated with reclaimed water (RW) were superior in all traits under study except the number of tillers/50 cm which did not show significant difference at $p < 0.05$ (Table 4). The wheat plant height was the highest (71.28 cm) under reclaimed water irrigation followed by groundwater (65.07 cm) and desalinated water irrigation

Table 3 Average values of EC (dS/m), pH, nitrogen mg l^{-1}, cations and anions for the three irrigation water types

Parameter	Unit	Groundwater	Desalinated water	Reclaimed water
ECw	dS/m	0.97	1.06	0.88
pH	–	7.8	7.5	7.7
Nitrogen N–NO_3^- (nitrate)	mg l^{-1}	14.31	0.463	28.70
Phosphate PO_4^{3-}	mg l^{-1}	0.074	Nd	9.413
Potassium K^+	mg l^{-1}	3.626	17.83	22.93
Cations and Anions				
Sulfate SO_4^{2-}	mg l^{-1}	78.77	39.87	81.17
Bicarbonate HCO_3^-	mg l^{-1}	209.27	152.53	107.99
Carbonate CO_3^{2-}	mg l^{-1}	Trace	Trace	Trace
Calcium Ca^{2+}	mg l^{-1}	15.43	38.91	58.21
Magnesium Mg^{+2}	mg l^{-1}	41.21	30.01	20.29
Sodium Na^+	mg l^{-1}	109.90	140.07	94.07
Chloride Cl^-	mg l^{-1}	125.84	276.49	140.02
Zinc Zn^{+2}	mg l^{-1}	0.446	0.461	0.546
Copper Cu^+	mg l^{-1}	0.026	0.026	0.027
Manganese Mn^{+2}	mg l^{-1}	0.004	0.011	0.048
Nickel Ni	mg l^{-1}	0.042	0.04	0.019
Boron B	mg l^{-1}	0.279	1.269	0.799
Molybdenum Mo	mg l^{-1}	0.063	0.083	0.112
Silicon Si	mg l^{-1}	0.187	0.974	0.959
Vanadium V	mg l^{-1}	0.01	0.064	0.043
Cobalt Co^{+2}	mg l^{-1}	0.303	0.320	0.250
Lead Pb^{4+}	mg l^{-1}	Nd	Nd	Nd
Chromium Cr^{+2}	mg l^{-1}	0.022	Nd	Nd
Cadmium Cd^{+2}	mg l^{-1}	Nd	Nd	Nd
Copper Cu^+	mg l^{-1}	Nd	Nd	Nd
Barium Ba^{+2}	mg l^{-1}	0.048	0.069	0.072
Sulfide S^{-2}	mg l^{-1}	Nd	5.581	22.97
Aluminum Al^{+3}	mg l^{-1}	0.088	0.096	0.093

Nd not detected

(63.60 cm). Plants receiving RW irrigation gave higher chlorophyll (49.92), leaf area (12.85 cm^2) and leaf length (16.13 cm) in comparison with those irrigated with GW and DW. The analysis of variance showed significant differences between the water types in grain yield and water productivity. However, there were no significant differences among the water types on their effect on straw yield (t ha^{-1}), biological yield (t ha^{-1}) and harvest index (Table 5). The wheat yielded 4.53 t ha^{-1} under reclaimed water irrigation followed by groundwater (3.81 t ha^{-1}) which did not significantly differ from desalinated irrigation water (3.49 t ha^{-1}). Jun-feng et al. (2007) found that wheat grain yield to be 5.8 t ha^{-1} under reclaimed water irrigation in experiments conducted in Dongzhi, China. Kang et al. (2002) found the grain yield to be from 1.77 to 4.92 t ha^{-1} under reclaimed water depending on the amount of water applied and the time of irrigation. RW irrigated plots increased wheat grain and biological yield by 18.90 and 9.59 %, respectively, as compared to GW irrigated plots. When evaluating agricultural production from the viewpoint of water use, the term water productivity refers to production per unit of water used with units kg m^{-3}. The WP of wheat grains was 0.98 kg m^{-3} under reclaimed water followed by 0.84 and 0.75kg m^{-3} under groundwater and desalinated water, respectively (Table 5). The values of WP in this study were in agreement with those (0.73–0.93 kg/m^3) for winter wheat (Kang et al. 2002) in Xian, Shaanxi, China. However, they were lower (ranged from 0.99 to 1.20 kg/m^3) than what has been stated by Abd El-Rahman (2009).

Effect of reclaimed water irrigation on cowpea crop

The results of statistical analysis indicated significant differences ($p < 0.05$) between the irrigation water types with respect to all characters of cowpea crop under study. The pods per plant (11 pods/plant) and seeds per pod (11

Table 4 Wheat plant height, no of tillers, chlorophyll, leaf area (cm^2) and leaf length (cm) for different types of water irrigation

Treatment	Plant height (cm)	No. of tillers/50 cm	Chlorophyll (SPAD-52)	Leaf area (cm^2)	Leaf length (cm)
Groundwater	65.07^b	55.00	46.25^b	9.80^b	13.92^b
Desalinated water	63.60^b	63.83	44.85^b	9.60^b	14.87^{ab}
Reclaimed water	71.28^a	53.50	49.92^a	12.85^a	16.13^a
Statistical parameters					
F-test (α = 5 %)	**	NS	**	**	*
LSD (5 %)	3.61	–	2.64	0.77	1.62
CV %	4.2	20.25	4.36	5.54	8.39

Means followed by similar letters are not significantly different

NS not significant

* Significant at $p < 0.05$

** Significant at $p < 0.01$

Table 5 Means of grain yield (t ha^{-1}), straw yield (t ha^{-1}), biological yield (t ha^{-1}), harvest index (%) and WP (kg grain m^{-3}) for different types of water irrigation

Treatment	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)	WP (kg grain m^{-3})
Groundwater	3.81^b	6.41	10.22	0.37	0.84^{ab}
Desalinated water	3.49^b	6.55	10.00	0.35	0.75^b
Reclaimed water	4.53^a	6.67	11.20	0.41	0.98^a
Statistical parameters					
F-test (α = 5 %)	*	NS	NS	NS	*
LSD (5 %)	0.66	–	–	–	0.14
CV %	12.97	23.31	16.33	15.35	13.08

Means followed by similar letters are not significantly different

NS not significant

* Significant at $p < 0.05$

** Significant at $p < 0.01$

seeds/pod) were higher in plants irrigated with reclaimed water in comparison with those irrigated with groundwater and desalinated water. The reclaimed water showed highest chlorophyll (61.18) in cowpea leaves, whereas the groundwater (56.87) and reclaimed water (56.03) did not significantly differ (Table 6). Cowpea plants irrigated with groundwater and desalinated irrigation water were not significantly different in total fresh yield. The cowpea fresh yield irrigated with groundwater (13.65 t ha^{-1}) and desalinated water (13.07 t ha^{-1}) was significantly lower than the plants irrigated with reclaimed water (15.74 t ha^{-1}). Akhtar and Nadaf (2002) reported the green forage yield of cowpea on an average was 40–50 t ha^{-1} for 2–3 cuts in a season which were higher than the values obtained in this study. However, Mupangwa et al. (2012) reported the yield of cowpea levels of 8 and 10 t ha^{-1} under mulch. The results in Table 7 indicate significant differences ($p < 0.05$) between the water types for all dry yield attributes except the dry forage yield. It is evident that dry yield for both the plants (3.36 t ha^{-1}) and pods (0.65 t ha^{-1}) was higher in reclaimed water treatments. This was reflected in the WP, in which the reclaimed water had significantly higher WP. The harvest index is the ratio of the pods weight to the total fresh weight in percentage. It was the highest (15.57 %) in the plants irrigated with reclaimed water followed by groundwater (11.47 %) then the desalinated water (7.58 %). The superiority in harvest index in reclaimed water was observed because of the high pod yield in plants irrigated with RW.

Effect of reclaimed water irrigation on maize crop

The effect of reclaimed water on plant height (cm), chlorophyll, leaf width (cm) and leaf length (cm) of maize crop is presented in Table 8. The statistical analysis indicated significant differences ($p < 0.05$) in plant height (cm), chlorophyll and leaf length (cm) among the treatments (water types). However, no significant difference ($p < 0.05$) was found between the treatments with respect to leaf width (Table 8). The results showed superiority of reclaimed water irrigation with respect to plant height (128.67 cm), chlorophyll (40.53)

Table 6 Chlorophyll, number of pods per plant, number of seeds per pod and fresh yield (t ha^{-1}) of cowpea crop under three types of irrigation water

Treatment	Chlorophyll	No of pods per plant	No of seeds per pod	Total Fresh fodder yield (t ha^{-1})	Total Fresh pod yield (t ha^{-1})	Total fresh yield (t ha^{-1})
Groundwater	56.87^{b}	7^{b}	10^{a}	12.18^{b}	1.75^{ab}	13.65^{b}
Desalinated water	56.03^{b}	6^{b}	8^{b}	11.01^{b}	0.94^{b}	13.07^{b}
Reclaimed water	61.18^{a}	11^{a}	11^{a}	14.46^{a}	2.49^{a}	15.74^{a}
Statistical parameters						
F-test (α = 5 %)	**	**	**	*	**	*
LSD (5 %)	2.35	2.80	1.32	2.13	0.854	1.875
CV %	3.15	28	11	13.21	38.48	10.3

Means followed by similar letters are not significantly different

NS not significant

* Significant at $p < 0.05$

** Significant at $p < 0.01$

Table 7 Means of dry yield (t ha^{-1}), harvest index (%) and water productivity (kg/m^3) of cowpea crop under the three types of irrigation water

Treatment	Dry forage yield (t ha^{-1})	Dry pod yield (t ha^{-1})	Total dry yield (t ha^{-1})	Harvest index (%)	WP (kg dry m^{-3})	WP (kg fresh m^{-3})
Groundwater	3.07	0.41^{b}	3.49^{ab}	11.47^{b}	0.23^{ab}	0.90^{b}
Desalinated water	2.82	0.23^{b}	3.05^{b}	7.58^{b}	0.20^{b}	0.84^{b}
Reclaimed water	3.36	0.65^{a}	4.01^{a}	15.57^{a}	0.26^{a}	1.02^{a}
Statistical parameters						
F-test (α = 5 %)	NS	**	**	*	**	**
LSD (5 %)	–	0.24	0.55	5.26	0.04	0.12
CV %	11.26	43.91	12.13	35.46	12.14	10.31

Means followed by similar letters are not significantly different

NS not significant

* Significant at $p < 0.05$

** Significant at $p < 0.01$

and leaf length (58.67 cm). The chlorophyll was found to be higher in the plants irrigated with reclaimed water (40.53) compared to those irrigated with groundwater (36.82) and desalinated water (35.95). Chlorophyll values (40.40) were similar to those reported by Adriel et al. (2005) in irrigation with RW and complete mineral fertilization. The analysis of variance indicated significant differences ($p < 0.05$) among the treatments (irrigation water types) in all the traits under study (Fresh and Dry yield and WP). However, the GW and DW did not significantly differ at $p < 0.05$ (Table 9). The total fresh (green) yield has found to be 35.87 t ha^{-1}, and the total dry yield was 12.46 t ha^{-1} for RW irrigation. Alkhamisi et al. (2011) found that the maize plants irrigated by reclaimed water gave higher green (43 t ha^{-1}) and dry (16 t ha^{-1}) forage yield than fresh water irrigation. WP of the plants, which were irrigated by reclaimed water, was found to be 1.19 kg m^{-3}.

Effect of reclaimed water irrigation on crops chemical contents

Nitrogen contents (%)

Nitrogen contents (%) in plant tissues and grains for wheat, cowpea and maize crops are presented in Fig. 1. The statistical analysis indicated that significant differences between the water types did not exist with respect to N contents in plant tissues and grains for wheat, cowpea and maize crops. The wheat grains showed the highest N concentration (2.30–2.55 %) followed by maize (1.69 to 1.85 %). The lowest N were found in cowpea (0.34–0.42 %). Tandon (1999) stated the sufficiency limit of nitrogen as 1.75–3.0 % for wheat, 4.0–6.0 % for peas and 3.5–5.0 % for maize.

Table 8 Effect of reclaimed water on plant height (cm), chlorophyll, leaf width (cm) and leaf length (cm) of maize crop

Treatment	Plant height (cm)	Leaf Chlorophyll (SPAD-52)	Leaf width (cm)	Leaf length (cm)
Groundwater	109.50[b]	36.82[b]	3.68	51.17[b]
Desalinated water	108.50[b]	35.95[b]	3.90	51.67[b]
Reclaimed water	128.67[a]	40.53[a]	4.28	58.67[a]
Statistical parameters				
F-test (α = 5 %)	**	**	NS	**
LSD (5 %)	10.50	2.50	–	4.14
CV %	7.06	5.34	11.87	5.98

Means followed by similar letters are not significantly different

NS not significant

** Significant at $p < 0.01$

Table 9 Effect of reclaimed water on fresh yield (t ha^{-1}), dry yield (t ha^{-1}) and WP (kg/m^3) of maize crop

Treatment	Plant fresh yield (t ha^{-1})	Cob fresh yield (t ha^{-1})	Total fresh yield (t ha^{-1})	Plant dry yield (t ha^{-1})	Cob dry yield (t ha^{-1})	Total dry yield (t ha^{-1})	WP (kg dry m^{-3})
Groundwater	9.73[b]	8.53[b]	18.27[b]	2.76[b]	3.27[b]	6.02[b]	0.57[b]
Desalinated water	11.07[b]	10.20[b]	21.27[b]	2.77[b]	3.30[b]	6.07[b]	0.58[b]
Reclaimed water	19.07[a]	16.80[a]	35.87[a]	5.79[a]	6.67[a]	12.46[a]	1.19[a]
Statistical parameters							
F-test (α = 5 %)	**	**	**	**	**	**	**
LSD (5 %)	3.033	3.598	5.595	1.223	2.034	2.398	0.229
CV %	17.74	23.62	17.3	25.21	35.85	22.78	22.74

Means followed by similar letters are not significantly different

NS not significant

* Significant at $p < 0.05$

** Significant at $p < 0.01$

Elements concentrations in wheat, cowpea and maize

Concentrations of different elements in wheat straw under irrigation of groundwater, desalinated and reclaimed water are presented in Table 10. Food and Agriculture Organization (FAO 2007) guidelines stipulate the permissible limits as: cadmium 0.2, copper 40, iron 450, zinc 60, manganese 500, chromium 5, lead 5 and nickel: 10 mg kg^{-1}. The results of the statistical analysis indicated the absence of significant difference ($p < 0.05$) between the three irrigation water types among all the elements except nickel (Ni) concentration. Plants irrigated with reclaimed water contained the highest Ni (0.079 (mg kg^{-1})) followed by desalinated water (0.073 (mg kg^{-1})) which did not significantly differ from reclaimed water. However, the lowest Ni concentration was in the plants irrigated with groundwater (0.029 (mg kg^{-1})). The average element concentrations are in the following order V < Ba < Mn < Ni < Cu < Pb < Mo < Co < Fe < Zn < Al < Si < B< P < Mg < Na < Ca < K< S. Concentrations of different elements in wheat grains under irrigation with groundwater, desalinated and reclaimed water are presented in Table 10. All the elements concentrations did not show any significant differences ($p < 0.05$) between irrigation water types. Only Cu and Mo were higher with the irrigation of reclaimed water. The average elements concentrations in wheat grains were in the following order: Mo < Ba < V< Cu < Ni < Pb < Co < Al < Si < B<Mn < Zn < P< Mg < Na < K < S. Elements concentrations in cowpea tissue under three water irrigation types are shown in Table 11. There were no significant differences between the three water irrigation types at $p < 0.05$ among all element concentrations. Despite the absence of significant difference between water types among the elements, the plants irrigated with RW were higher in some elements like Mg, B, Co and Si. The concentrations of those elements were 3.839, 1.297, 0.020 and 0.291 (mg kg^{-1}), respectively, under reclaimed water. The average elements concentrations were in the following order: Co < Si < Al < Fe < B< Mg < Na < Ca < Zn < S. Elements concentrations in cowpea pods under groundwater, desalinated and reclaimed

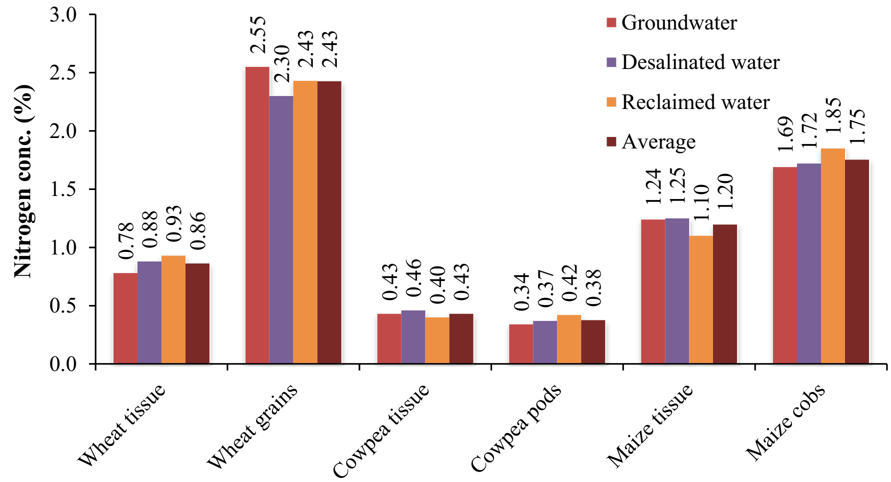

Fig. 1 Nitrogen contents (%) in plant tissues and grains for wheat, cowpea and maize

Statistical parameters

	Wheat tissue	Wheat grains	Cowpea tissue	Cowpea pods	Maize tissue	Maize cobs
F-test (p<0.05)	NS	NS	NS	NS	NS	NS
CV %	18.78	7.02	15.09	21.86	13.49	14.24

NS = Not significant

Table 10 Concentrations of different elements in wheat straw and grains under groundwater (GW), desalinated (DW) and reclaimed water (RW)

Element (mg kg^{-1})	Wheat straw			*F*-test (5 %)	Wheat grains			F-test (5 %)
	GW	DW	RW		GW	DW	RW	
Al	0.59	0.48	0.48	NS	0.68	0.65	0.59	NS
B	1.53	1.48	1.49	NS	1.50	1.28	1.33	NS
Ba	0.02	0.03	0.03	NS	0.05	0.05	0.05	NS
Ca	7.11	7.53	6.64	NS	–	–	–	–
Co	0.27	0.28	0.28	NS	0.3	0.28	0.27	NS
Cu	0.10	0.06	0.05	NS	0.08	0.06	0.09	NS
Fe	0.40	0.41	0.33	NS	–	–	–	–
K	118	100	109	NS	818	887	813	NS
Mg	3.92	3.91	2.64	NS	16.58	17.77	13.9	NS
Mn	0.06	0.07	0.06	NS	1.78	3.9	2.46	NS
Mo	0.03	0.04	0.07	NS	0.04	0.03	0.07	NS
Na	5.76	5.89	5.84	NS	314	263	261	NS
Ni	0.03[b]	0.07[a]	0.08[a]	*	0.07	0.07	0.08	NS
P	3.79	2.84	2.81	NS	12.50	12.56	10.58	NS
Pb	0.11	0.12	0.16	NS	0.17	0.24	0.17	NS
S	2579	2158	2385	NS	6626	7874	7753	NS
Si	0.63	0.55	0.57	NS	0.80	1.00	0.92	NS
V	0.02	0.01	0.01	NS	0.06	0.06	0.06	NS
Zn	0.76	0.27	0.39	NS	3.57	2.70	2.14	NS

[a] Means followed by similar letters are not significantly different at $p<0.05$

* Significant at $p < 0.05$

NS not significant

Table 11 Concentrations of different elements in cowpea tissue and pods under groundwater (GW), desalinated (DW) and reclaimed water (RW)

Element (mg kg^{-1})	Cowpea tissue			*F*-test (5 %)	Cowpea pods			F-test (5 %)
	GW	DW	RW		GW	DW	RW	
Al	0.43	0.36	0.38	NS	0.25	0.25	0.25	NS
B	1.23	1.22	1.3	NS	1.39	1.41	1.43	NS
Ca	8.6	7.55	7.04	NS	–	–	–	–
Co	0.02	0.02	0.02	NS	0.02	0.02	0.02	NS
Fe	0.6	0.43	0.43	NS	0.40	0.39	0.37	NS
Mg	2.5	3.25	3.84	NS	–	–	–	–
Na	3.57	3.17	3.53	NS	2.95	2.97	2.70	NS
S	1723	1910	1861	NS	2075	2187	2104	NS
Si	0.27	0.27	0.29	NS	0.29	0.31	0.30	NS
Zn	323	249	143	NS	250	263	203	NS

NS not significant

Table 12 Concentrations of different elements in maize tissue and grains under groundwater (GW), desalinated (DW) and reclaimed water (RW)

Element (mg kg^{-1})	Maize tissue			*F*-test (5 %)	Maize grains			F-test (5 %)
	GW	DW	RW		GW	DW	RW	
Al	0.8	0.71	0.84	NS	1.07	0.85	0.51	NS
B	0.98	0.93	0.92	NS	1.06	0.91	0.92	NS
Ca	11.27	13.00	13.43	NS	14.94	20.77	35.8	NS
Co	0.02	0.02	0.02	NS	0.03	0.02	0.02	NS
Fe	1.23	1.03	1.17	NS	1.35	1.23	1.32	NS
K	1.29	1.22	1.96	NS	2.58	3.28	3.80	NS
Mg	27.13	26.31	26.54	NS	22.81	28.30	24.63	NS
Mn	0.11^{a}	0.06^{b}	0.07^{b}	**	0.11	0.15	0.14	NS
Mo	0.04	0.04	0.03	NS	0.06	0.03	0.04	NS
Na	4.73^{b}	10.07^{a}	4.29^{b}	*	4.87	6.13	6.32	NS
Ni	0.03	0.03	0.02	NS	0.02	0.04	0.04	NS
S	2696	2582	2795	NS	2612	2757	2850	NS
Si	0.08	0.09	0.09	NS	0.10	0.11	0.19	NS
Zn	251	264	344	NS	356	355	513	NS

[a] Means followed by similar letters are not significantly different at $p<0.05$

NS not significant

* Significant at $p < 0.05$

water irrigations are presented in Table 11. The results showed no significant differences ($p < 0.05$) between the water types among all elements concentrations. Despite the absence of the significant differences (p < 0.05), only B concentration was the highest in reclaimed water irrigation. Elements concentrations in cowpea pods were in the following order: Co < Al < Si < Fe < B < Na < Zn < S. All the elements concentration in cowpea tissue and pods were found to be relatively lower than the critical limits in plants according to Alloway (1995). Table 12 presents the concentrations of different elements in maize plants under groundwater, desalinated and reclaimed water irrigation. The statistical analysis revealed the absence of any significant differences ($p < 0.05$) between the water types except Na and Mn concentrations. Na showed the highest concentration in maize tissues irrigated with desalinated water (10.07 mg kg^{-1}) followed by groundwater (4.73 mg kg^{-1}) which did not significantly differ from the reclaimed water (4.29 mg kg^{-1}). Maize plants irrigated with desalinated water (0.112 mg kg^{-1}) were the highest in Mn concentration followed by reclaimed water (0.07 mg kg^{-1}) which did not significantly differ from the groundwater (0.06 mg kg^{-1}). Despite the lack of significant differences between the irrigation water types, the reclaimed water was superior in Si, Zn, Al, K and Ca elements concentrations (Table 12). The average elements concentrations in maize were in the following order: Co < Ni < Mo < Mn < Si < Al < B < Fe < K < Na < Ca < Mg < Zn < S. Zn was found to be relatively lower than the critical limits in plants (100–900 (mg kg^{-1})) according to Alloway (1995). Concentrations of different elements in maize grains under irrigations of reclaimed, desalinated and groundwater are illustrated in Table 12. The statistical analysis indicated no significant differences ($p < 0.05$) between water types among all elements. Despite the lack of the significant differences ($p < 0.05$), plants irrigated with reclaimed were the highest in Na, K, Ca, Zn, Si, Ni and S concentrations in maize cobs. Elements concentrations in maize cobs were in the following order: Co < Ni < Mo < Si < Mn < Al < B< Fe < K < Na < Ca < Mg < Zn < S.

Conclusions

From the results, it is concluded that the effect of RW was obvious on wheat agronomic characters. All of the traits were higher under RW irrigation except number of tillers, straw yield, biological yield and harvest index (%). Cowpea plants irrigated by RW showed superiority in all traits except the dry forage yield. Furthermore, the growth parameters of maize increased after irrigation by RW. N concentration was higher under RW irrigation in wheat tissues, cowpea pods and maize cobs. The other element concentrations were not affected by RW irrigation; except Ni in wheat plants where the highest was under RW compared to DW and GW, and Na and Mn in maize plants. Generally, wheat grains, cowpea pod and maize cobs were not affected by the RW irrigation with respect to all the studied element concentrations. It can be concluded that there was no adverse impact of reclaimed water irrigation on yield and chemical characteristics of plants and grains of crops under study. The positive influence of RW on yield and WP is significant.

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