RESEARCH ARTICLE

Sewage waste water application improves the productivity of diverse wheat (*Triticum aestivum* L.) cultivars on a sandy loam soil

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Abstract

Water stress due to climate change is an emerging threat to wheat (*Triticum aestivum* L.) productivity in the arid regions of the world which will impact the future food security. In this scenario, the investigations are needed to check the feasibility of alternate sources of irrigation water to fulfill the irrigation demands of the crops in the arid regions. This 2-year study was aimed to investigate the influence of three irrigation sources (sewage water, canal water, and underground water) on the productivity of 10 wheat cultivars under an arid climate of Layyah, Pakistan. The results indicated that the number of fertile tillers, grains per spike, 1000-grain weight, and grain yield varied from 114 to 168 m^{-2}, 34.8 to 53.3, 33.4 to 38.4 g, and 2.68 to 4.05 Mg ha^{-1}, respectively in various wheat cultivars. The highest fertile tillers (168 m^{-2}) were recorded in cultivar Gold-2016 followed by Aas-2011 (155 cm), AARI-2011 (153 m^{-2}), and Ujala-2016 (150 m^{-2}). The highest 1000-grain weight of 38.4 g was recorded in cultivar NARC-2016. The grains per spike (53.3) were the highest in cultivar Ujala-2016. The grain yields were the highest in cultivars Ujala-2016 (4.05 Mg ha^{-1}) and Gold-2016 (3.91 Mg ha^{-1}). The highest grain yield of 3.71 Mg ha^{-1} was recorded with sewage water irrigation against the grain yield of 3.18 and 2.91 Mg ha^{-1} in canal and underground water irrigation, respectively. There existed a strong co-relation of fertile tillers and grains per spike with the grain yield of wheat. Application of sewage water also enhanced the total nitrogen, extractable potassium, and available phosphorous in soil. In crux, the cultivation of recently bread wheat cultivars (viz. Ujala-2016, Gold-2016) and the irrigation of field with sewage water in the absence of canal water might be a viable option to boost wheat productivity under arid regions. A range of genetic variability existed for different traits in the cultivars; therefore, these can be used to breed wheat cultivars to be used for sewage water cultivation.

Keywords Climate change; Bread wheat · Water shortage · Sewage water · Canal water · Arid climate · Wheat productivity · Food security

Introduction

Bread wheat (*Triticum aestivum* L.) is the most important cereal and staple food of the world which provides basic nutrition to the world population (Ul-Allah 2018). It is grown in an area of > 220 million ha of the world under diverse environmental and geographical locations (FAO 2016). Its overall production in the world is more than ~ 749 million tons (FAO 2016). The average yield of wheat in developing countries is 15% lower than that of the developed countries (FAO 2016). The main reasons for lower wheat yields are low genetic potential of available wheat cultivars, less availability and lower quality of irrigation water, and poor management of biotic and abiotic stresses (Rehman et al. 2015).

The semi-arid and arid regions occupy 30% of the total land area within 80 countries of the world, mainly in Asia and Africa; 40% of the world population lives in these areas. In arid areas, the annual rainfall is less than 250 mm and the irrigation facilities are also limited (Sivakumar et al. 2011) which hampers the crop productivity in these areas. The depletion of surface water resources and aquifers is also threating the future water utilization patterns (Qureshi 2015; Mekonnen et al. 2016; Wada 2016) in arid regions of the world which will impact the wheat productivity and ultimately

the food security. It has been reported that the water scarcity will be double in the next 30 years, especially in arid and semi-arid regions of the world (Balon and Dehnad 2006). Khan et al. (2006) reported that the water availability is expected to decline from 72 to 62% from 1995 to 2020. Moreover, the competition for fresh water due to rapid urbanization and industrialization will also reduce the availability of water for agriculture (Cumming et al. 2014; Jabeen et al. 2015; Shao et al. 2017) in the near future.

Indeed, the seasonal water stress due to uneven distribution of rainfall (Farooq and Siddique 2016; Nyagumbo et al. 2017; Chalise et al. 2017) limits the crop development and yield to a large extent in many parts of the world. Many studies have reported that water stress reduces the productivity of bread wheat in many regions of the world (Alexieva et al. 2001; Nawaz et al. 2013) resulting in food insecurity.

Thus, it is essential to search for alternative resources of water for maximizing the wheat production to fulfill the dietary needs of the human population. Beside canal water, there are some other water sources (e.g., sewage water and underground water) which can be used for irrigation purposes in the future. Indeed, the sewage water consists of several macro- and micro-nutrients which can improve the crop growth (Singh and Agrawal 2008; Srinivas et al. 2014; Anwar et al. 2016; Galal and Shehata 2015). For example, Rattan et al. (2005) found a high amount of phosphorus, potassium, sulphur, zinc, and manganese in sewage water which improved the soil organic matter contents (38–79%) than the underground water. Sewage water application also reduced the soil pH by 0.4 units. The tissue lead and cadmium concentration was also within the permissible limit due to sewage water application (Rattan et al. 2005).

For this study, we hypothesized that the use of sewage water might be a useful alternative to canal and underground water for sustainable wheat production in arid regions. The specific objective of this study was to investigate the response of different wheat cultivars to different irrigation resources (i.e., canal water, sewage water, and tube well water) under an arid climate.

Materials and methods

Experimental site, soil, and weather

This 2-year study was conducted at the Research Area of the College of Agriculture, Bahauddin Zakariya University, Bahadur Sub-Campus Layyah (latitude 31.25° N and longitude 73.09° E), Punjab, Pakistan, during 2015–2016 and 2016–2017. The weather data including the temperature and rainfall is given in Table 1. The experimental soil was sandy loam with soil pH of 8 and electrical conductivity of 0.31 dS m^{-1}. The post-harvest soil analysis revealed that the soil irrigated with canal water, tube well water, and sewage water had pH of 7.71–7.80, 7.93–8.01, and 8.05–8.08, respectively during both years. The post-harvest soil electrical conductivity for canal water, tube well water, and sewage water irrigated plots was 0.31–0.33, 0.38–0.45, and 0.36–0.37, respectively during both years.

Experimental design

The experiment was laid out in randomized complete block design (RCBD) in split plot arrangement keeping three irrigation water sources (household sewage water, canal water, and underground water) in main plots and ten wheat cultivars (i.e., Galaxy-2013, Sehar-2006, AARI-2011, Gold-2016, NARC-2016, Ujala-2016, Faisalabad-2008, Punjab-2011, Aas-2011, and Lasani-2008) in sub plots having four replications with a net plot size of 7.5 m × 1.80 m. There were eight rows of each cultivar in an individual plot, which were 25 cm part. These ten wheat cultivars are widely grown in the province of Punjab, Pakistan, as they are high yielding, have better resistance to fungal diseases, and can better cope with the abiotic stresses including drought and heat in the arid and semi-arid of the country.

Crop husbandry

Seeds of all the wheat varieties were sown on November 11 and 16 during 2015 and 2016, respectively at a

Table 1 Weather data during the experimental period at the experimental site

Months	Rainfall (mm)		Maximum temperature (°C)		Minimum temperature (°C)	
	2015–2016	2016–2017	2015–2016	2016–2017	2015–2016	2016–2017
November	17.0	15.3	25.22	24.01	13.1	12.0
December	9.20	5.8	22.75	23.10	6.21	5.90
January	31.3	48.8	19.63	18.16	5.90	6.5
February	22.0	19.1	22.36	23.56	8.80	8.22
March	25.0	27.6	28.55	27.43	15.26	14.13
April	9.0	5.0	37.45	37.15	20.21	20.24

Agro-meteorological center, Karor Lal Eason, Layyah

recommended seed rate of 100 kg ha^{-1}. The row to row distance was maintained at 22.5 cm. Based on soil analysis report, nitrogen (N), phosphorus (P), and potassium (K) were applied at the rate of 100, 90, and 75 kg ha^{-1}, respectively. Sulfate of potash (50% K_2O), urea (46% N), and diammonium phosphate (DAP) (18%N, 46% P_2O_5) were used as source of K, N, and P, respectively. Full P and K and half N were applied at sowing; the remaining N was applied at the first and second irrigation. Weeds were controlled manually (through hand pulling) in the experimental plots. Pre-sowing irrigation of 100 mm was given before the sowing of crop to bring the experimental soil at field capacity for seed sowing. After the wheat sowing, five irrigations (each of 75 mm) were given to the crop during the entire life cycle. The irrigation was applied using the various irrigation water sources as per treatment. The sewage water was applied from a city sewage water collection unit situated 2 km away from the experimental site via an irrigation channel. The properties of three irrigation water sources used in the study are given in Table 2. Crop was harvested on April 18, 2016 and April 20, 2017 at harvest maturity. Each plot was harvested separately and was threshed to record the yield and other related traits.

Data recording

Morphological and yield parameters

Data on plant height, fertile tillers, spike length, 1000-grain weight, grains per spike, and grain yield was recorded following the standard procedures as detailed in Farooq and Nawaz (2014) and Nawaz et al. (2016). Straw yield was recorded by threshing the harvested wheat samples from each plot and after separating the straw from the seed using a mini-thresher, and straw yield was later expressed in Mg ha^{-1}. The harvest index was calculated as the ratio of biological yield (straw yield + grain yield) to the grain yield, expressed in percentage.

Soil properties

Soil pH and electrical conductivity were measured in 1:2.5 soil water moisture using Thermo Scientific Orion 4-star meter (Thermo Fisher Scientific Inc., Beverly, MA). Data on total nitrogen (Bremner and Mulvaney 1982), available phosphorous (Olsen et al. 1954), extractable potassium (Richards 1954), and soil organic matter (Walkley and Black 1934) was recorded following the standard procedures as detailed elsewhere.

Determination of heavy metals

For the determination of heavy metals (chromium, copper, nickel, lead) in sewage water, a sample of 1 L sewage waste water was collected from the entrance point of water in the field. This 1-L sample was treated with 1.5 mL of concentrated HNO_3. From this, a 50-mL water sample in an evaporating dish was taken and evaporated on a steam bath until the volume of 20 mL was retained in dish. It was followed by an addition of 10 mL of 8 M HNO_3 (98% pure) in that 20-mL volume and was further evaporated to near dryness on a hot plate. The residue was quantitatively transferred using two aliquots of 10 and 15 mL of concentrated HNO_3 into a 250-mL flask. In this, 20 mL of $HClO_4$ was added followed by boiling until the solution became clear and white fumes of $HClO_4$ appeared. It was cooled and 50 mL of distilled water (de-ionized) was added followed by filtration of the solution. The resulting filtered solution was transferred to a volumetric flask of 100 mL volume in two portions of 5 mL distilled water (de-ionized). The solution was further diluted to mark and mixed thoroughly by shaking. Finally, the heavy metals under were determined by using an atomic absorption spectrophotometer (model AA-6300 Shimadzu). Copper and lead were within the permissible limits (Table 3). Nickel and chromium were within the permissible limits (Table 3) according to Chiroma et al. (2014) but were higher according to Pescod (1992). Thus, the uptake of these metals by wheat plant should be measured in the future studies.

Table 2 Properties of different water sources used for irrigation

Irrigation water source	pH	EC (dS m^{-1})	Ca^{+2} Mg^{+2} (meq L^{-1})	Na$^+$ (meq L^{-1})	CO$_3^-$	HCO$_3^-$ (meq L^{-1})	Cl$^-$	SAR	RSC (meq L^{-1})
Tube well water	7.21	0.778	6.41	1.37	Nil	5.40	–	Nil	0.76
Canal water	7.03	0.472	4.56	0.16	Nil	4.23	–	Nil	0.10
Sewage water	7.50	0.792	5.46	1.20	Nil	4.67	–	Nil	0.33

EC electrical conductivity, *Ca* calcium, *Mg* magnesium, *Na* sodium, *CO$_3$* carbonate, *HCO$_3$* bicarbonate, *SAR* sodium absorption ratio, *RSC* residual sodium carbonate

All the values are the average of 2 years

Table 3 Heavy metal concentration in sewage water during both experimental years

Heavy metal concentration	2016	2017	Permissible limit
Chromium (mg L^{-1})	0.40	0.39	0.55 (Chiroma et al. 2014) and 0.10 mg L^{-1} (Pescod 1992)
Copper (mg L^{-1})	0.15	0.16	0.20 (Pescod 1992; WHO/FAO 2007)
Nikel (mg L^{-1})	0.89	0.91	1.40 (Chiroma et al. 2014) and 0.20 mg L^{-1} (Pescod 1992)
Lead (mg L^{-1})	3.20	3.18	5.00 (Pescod 1992; WHO/FAO 2007)

Statistical analysis

After, recording data on all parameters, it was transferred into Microsoft Excel and was statistically analyzed with statistical software "Statistix 8.1" under randomized complete block design in split plot arrangement. The significance of treatment means was estimated by Fisher analysis of variance technique and the significant treatment means (main effects and interaction) were separated using least significant difference test at 5% probability level (Steel et al. 1997). Year effect was non-significant; thus, the data for both years has been pooled and presented.

Results

Morphological and yield parameters

This study indicated that different wheat cultivars significantly ($p \leq 0.05$) differed for plant height, fertile tillers, spike length, 1000-grain weight, grains per spike, straw yield, grain yield, and harvest index of wheat (Tables 4 and 5). Likewise, plant height, fertile tillers, 1000-grain weight, grains per spike, straw yield, and grain yield were significantly ($p \leq 0.05$) different among various irrigation sources, results being non-significant for spike length and harvest index (Tables 4 and 5). The interaction of wheat cultivars with the irrigation water sources was also significant ($p \leq 0.05$) for grain yield (Tables 4 and 5).

Among the wheat cultivars, the highest plant height (109 cm) and grains per spike (53.3) were recorded in cultivar Ujala-2016. The plant height was the lowest (68 cm) in cultivar Lasani-2008; grains per spike were the lowest (34.8) in Galaxy-2013 (Table 4). The fertile tillers were the highest (168 cm) in cultivar Gold-2016 and that were statistically similar with the cultivars Aas-2011 (155 cm), Ujala-2016 (153 cm), and AARI-2011 (150 cm) (Table 4). The spike length was the highest (11.2 cm) in cultivar Punjab-2011 and lowest in cultivars Galaxy-2013 (7.9 cm) and Sehar-2006 (7.9 cm) (Table 4). The 1000-grain weight was the highest (38.4 g) in cultivar NARC-2016 and lowest (33.4 g) in cultivar Galaxy-2013 (Table 4). The straw yield was the highest in AARI-2011 (7.3 Mg ha^{-1}) which was statistically similar with cultivar Galaxy-2013 (7.2 Mg ha^{-1}) and it was the lowest (6.5 Mg ha^{-1}) in cultivar Punjab-2011 (Table 4). A highest grain yield of 6.5 Mg ha^{-1} and harvest index of

38.4% were recorded in cultivar Gold-2016 which was statistically similar with cultivar Ujala-2016 for both parameters (Table 5). However, the lowest grain yield (2.7 Mg ha^{-1}) and harvest index (28.3%) were recorded in cultivar Galaxy-2013 which were statistically similar with cultivar Sehar-2006 and Lasani-2008 for grain yield (Table 5).

Among the water sources, the significantly ($p \leq 0.05$) highest plant height (100 cm), fertile tillers (156 m^{-2}), 1000-grain weight (37.5 g), grains per spike (45.8), straw yield (7.2 Mg ha^{-1}), and grain yield (3.71 Mg ha^{-1}) were recorded with sewage water irrigation and that were statistically similar with canal water for fertile tillers. Irrigation with underground water was not useful for wheat as was indicated by low values of morphological and yield parameters (Tables 4 and 5). The interaction [irrigation water sources (IW) × wheat cultivars (WC)] showed that the highest grain yield (4.64 Mg ha^{-1}) was recorded in Gold-2016 with canal water irrigation followed by sewage water irrigation in cultivars Ujala-2016 and Faisalabad-2008 (Table 4). Correlation analysis revealed a strong co-relation of fertile tillers ($p = 0.01$; $R^2 = 0.58$) and grains per spike ($p = 0.00$; $R^2 = 0.78$) with the grain yield of wheat (Figs. 1 and 2).

Soil properties

Different irrigation sources significantly affected the soil organic matter, total nitrogen, available phosphorus, and extractable potassium within the soil during both year of experimentation (Figs. 3, 4, 5, and 6). During both years, the highest soil organic matter was recorded with the application of sewage water; the canal water and tube well water were at par for improving the soil organic matter as compared with soil organic matter status at the start of experiment (Fig. 3). The significantly highest total nitrogen was recorded with sewage water application during both years or with canal water irrigation during the second year of experimentation. There was no significant improvement in total nitrogen and extractable potassium in soil with the addition of tube well water during both year compared with soil initial total nitrogen status (Figs. 4 and 5). The application of sewage water and canal water significantly enhanced the soil extractable potassium during both years of experiment (Fig. 5). The highest soil available phosphorus was detected in sewage water– and canal water–treated plots during the second year of experimentation (Fig. 6).

Table 4 Influence of various irrigation water sources on plant height (cm), fertile tillers (m^{-2}), spike length (cm), 1000-grain weight (g), grain per spike, and straw yield (Mg ha^{-1}) of different wheat cultivars

Treatments	Sewage water	Canal water	Tube well water	Mean (V)	Sewage water	Canal water	Tube well water	Mean (V)
	Plant height (cm)				Fertile tillers (m^{-2})			
Galaxy-2013	98	98	94	96D	152	147	137	145BC
Sehar-2006	107	104	102	104B	139	139	130	136BCD
AARI-2011	96	102	92	97D	160	166	133	153AB
Gold-2016	107	98	101	102BC	159	218	128	168A
NARC-2016	106	106	101	104B	145	135	124	135BCD
Ujala-2016	113	108	106	109A	183	136	131	150AB
Faisalabad-2008	104	102	99	102BC	178	116	146	147ABC
Punjab-2011	103	99	99	100C	132	129	114	125CD
Aas-2011	95	91	91	92E	181	148	137	155AB
Lasani-2008	70	66	67	68F	134	87	122	114D
Mean (IW)	100A	98B	95C		156A	142AB	130.3B	
LSD (p ≤ 0.05)	IW = 0.83, V = 3.25				IW = 0.83, V = 3.25			
	Spike length (cm)				1000-grain weight (g)			
Galaxy-2013	8.5	8.0	7.2	7.9D	34.8	32.7	32.8	33.4C
Sehar-2006	8.3	7.5	7.9	7.9D	37.0	35.4	35.2	35.9B
AARI-2011	7.6	8.3	9.0	8.3CD	36.5	35.7	35.9	36.0B
Gold-2016	10.0	9.4	8.9	9.4BC	36.5	35.8	35.8	36.1B
NARC-2016	10.0	8.8	7.6	8.8BCD	39.6	39.7	36.1	38.4A
Ujala-2016	9.6	7.9	8.9	8.8BCD	37.7	36.3	35.3	36.4B
Faisalabad-2008	10.3	9.2	9.7	9.7B	38.9	35.9	33.4	36.1B
Punjab-2011	12.0	11.6	10	11.2A	38.5	35.6	33.5	35.9B
Aas-2011	10.3	9.4	9.2	9.6B	38.3	34.9	35.5	36.2B
Lasani-2008	9.4	9.3	9.8	9.5BC	36.8	34.3	34.9	35.3B
Mean (IW)	9.6	9.0	8.8		37.5A	35.6B	34.8B	
LSD (p ≤ 0.05)	V = 1.26				IW = 1.25, V = 1.37			
	Grains per spike				Straw yield (Mg ha^{-1})			
Galaxy-2013	35.6	34.4	34.3	34.8E	6.2	7.9	7.5	7.2AB
Sehar-2006	41.0	38.7	38.4	39.4D	6.3	7.9	7.0	7.1ABC
AARI-2011	46.8	43.6	40.5	43.6C	7.7	7.9	6.4	7.3A
Gold-2016	49.4	46.6	48.0	48.0B	7.8	7.5	5.7	7.0A-D
NARC-2016	44.5	40.9	36.2	40.5D	7.9	6.3	6.6	6.9A-E
Ujala-2016	50.0	52.2	57.7	53.3A	7.4	6.3	6.6	6.8B-E
Faisalabad-2008	51.5	43.2	40.7	45.1C	7.5	6.6	6.6	6.9A-E
Punjab-2011	44.6	45.1	46.8	45.5BC	6.3	6.5	6.6	6.5E
Aas-2011	49.0	41.5	41.5	44.0C	7.4	6.3	5.9	6.5DE
Lasani-2008	45.7	38.2	38.6	40.8D	7.7	6.6	5.7	6.7CDE
Mean (IW)	45.8A	42.4B	42.3B		7.2A	6.99B	6.5C	
LSD (p ≤ 0.05)	for IW = 2.50, V = 2.70				for IW = 0.19, V = 0.46			

Means sharing same case letter, for main effects and interaction do not differ significantly at $p \leq 0.05$

Discussion

This study indicated that various wheat cultivars used in this study differed significantly ($p \leq 0.05$) for plant height, spike length, yield parameters (grain per spike, fertile tiller, 1000-grain weight), grain yield, straw yield, and harvest index. The variation in the performance of the different wheat traits may be attributed to different genetic makeups of the studied cultivars which are also associated with yield (Lopes et al. 2015; Sukumaran et al. 2015 2015). This genetic diversity may be used for the development of wheat cultivars to specific climatic conditions for maximum productivity (Araus and Cairns 2014; Ogbonnaya et al. 2017), especially under the arid climates.

Table 5 Influence of various irrigation water sources on grain yield (Mg ha^{-1}) and harvest index (%) of different wheat cultivars

Treatments	Sewage water	Canal water	Tube well water	Mean (V)	Sewage water	Canal water	Tube well water	Mean (V)
	Grain yield (Mg ha^{-1})				Harvest index (%)			
Galaxy-2013	2.89gj	2.66hij	2.54ij	2.70E	33.1	25.6	26.1	28.3F
Sehar-2006	3.11ei	2.91ghi	2.76hij	2.92E	33.6	27.6	29.5	30.2DEF
AARI-2011	3.74cf	3.58cg	2.94ghi	3.42BCD	33.4	32.0	34.2	33.2BC
Gold-2016	3.90ad	4.64a	3.21di	3.91A	33.7	38.8	37.9	36.8A
NARC-2016	3.43d-h	3.00f-i	2.59ij	3.00DE	30.9	33.1	29.9	31.3CDE
Ujala-2016	4.61ab	3.84b-e	3.71c-f	4.05A	39.8	38.5	36.9	38.4A
Faisalabad-2008	4.56ab	2.79hij	2.98f-i	3.44BC	38.5	30.1	32.1	33.5BC
Punjab-2011	3.24d-i	3.10f-i	2.78hij	3.04CDE	34.6	32.4	30.7	32.6CD
Aas-2011	4.35abc	3.14d-i	3.00f-i	3.49B	38.1	33.6	35.6	35.8AB
Lasani-2008	3.25d-i	2.13j	2.64hij	2.68E	30.7	25.2	32.6	29.5EF
Mean (IW)	3.71A	3.18B	2.91B		34.6	31.7	32.6	
LSD ($p \le 0.05$)	IW = 0.40, V = 0.42, IW × V = 0.7				V = 2.94			

Means sharing same case letter, for main effects and interaction do not differ significantly at $p \le 0.05$

In this study, the grain yield was highest in cultivar Ujala-2016 and Gold-2016 than other wheat cultivars. This grain yield was 50% higher in cultivar Ujala-2016 and 44.8% in Gold-2016, compared with the cultivar Galaxy 2013 which produced the lowest grain yield than other cultivars under the arid climate. The highest grain yields in cultivars Ujala-2016 and Gold-2016 were the outcome of higher value of related agronomic and yield traits (fertile tillers and grains per spike) which have positive association with yield as was indicated through the strong co-relation of fertile tillers ($p = 0.01$; $R^2 = 0.58$) and grains per spike ($p = 0.00$; $R^2 = 0.78$) with the grain yield of wheat (Figs. 1 and 2). Various previous studies have reported that wheat cultivars differ in morphological and yield

parameters (Denčić et al. 2000; Le Gouis et al. 2000; Gupta et al. 2001; Brancourt-Hulmel et al. 2003; Guarda et al. 2004; Barraclough et al. 2010; Mustățea and Saulescu 2011; Ul-Allah et al. 2018) which is quite helpful for breeding new wheat cultivar for specific traits under optimal and sub-optimal conditions.

The performance of some wheat cultivars was not consistent over different sources of irrigation water. For example, cultivars Ujala-2016 and Faisalabad-2008 produced highest yield with sewage water irrigation than other cultivars. However, cultivar Gold-2016 and Ujala-2016 produced the highest grain yield when irrigated with canal water and sewage water respectively. These differences might be due to
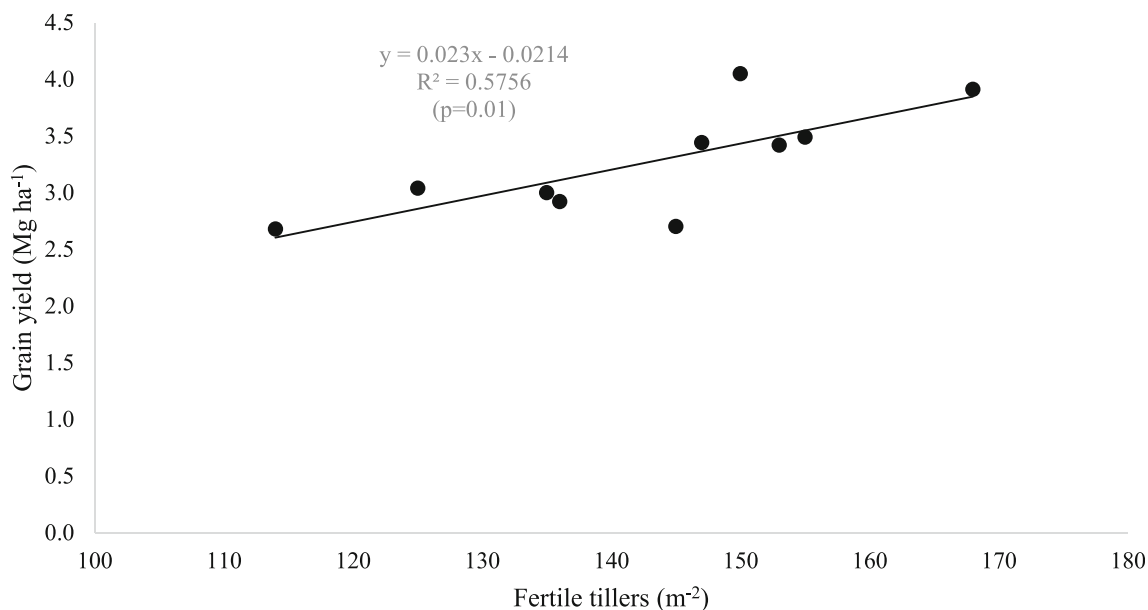
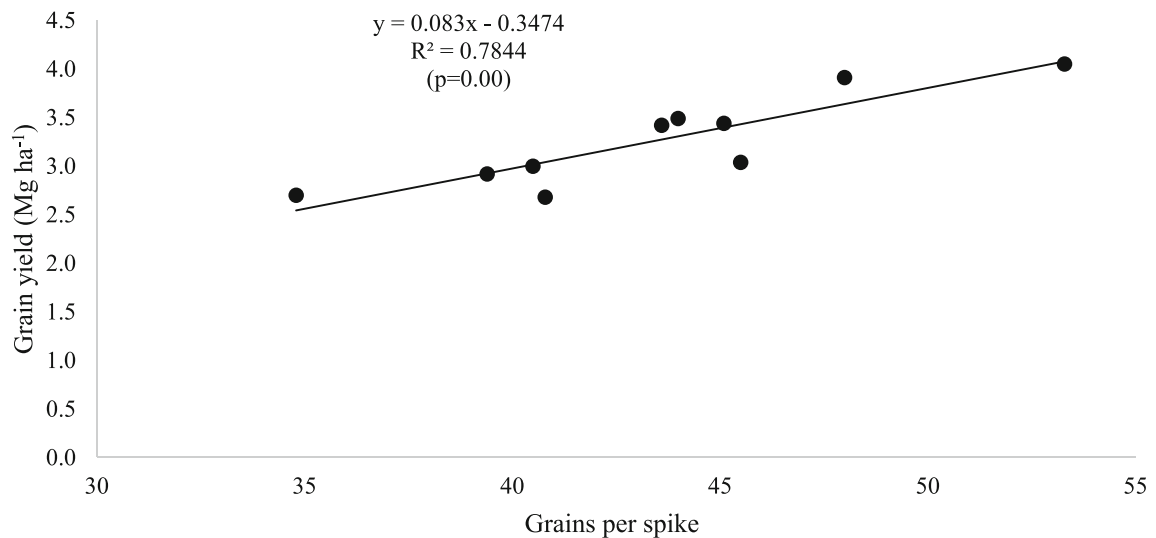**Fig. 1** Regression co-efficient of fertile tillers with grain yield

Fig. 2 Regression co-efficient of grains per spike with grain yield

genetic makeup adoptive to specific environmental and soil conditions (Araus and Cairns 2014; Richard et al. 2015). These cultivars must be used in breeding programs focused on specific environment and soil inputs.

Overall performance of wheat cultivars was better under sewage and canal water than underground water supplied by tube well. The better morphological and yield parameters due to sewage water might be attributed to the presence of significant amount of macronutrients (e.g., nitrogen, phosphorus, potassium) (Figs. 4, 5, and 6) and micro-nutrients in sewage water (Srinivas et al. 2014; Galal and Shehata 2015) and canal water which improve the soil chemical properties (Qaryouti et al. 2015; Mekonnen et al. 2016; Yaseen et al. 2016) resulting in improved microbial activity, plant nutrient availability, and better yield. In another study, Rattan et al. (2005) reported that the application of sewage water enhanced the zinc, manganese, potassium, sulphur, and phosphorus contents in the soil which

improved the soil organic matter with simultaneous reduction in soil pH (Rattan et al. 2005). Anwar et al. (2016) also found that the potassium and phosphorus concentration in the roots, shoot, and leaves of different vegetables was increased with sewage water irrigation. Although, we have not evaluated the effect of water sources on nutritional quality of wheat in this study; nonetheless, many studies have reported that sewage water may have detrimental effect on nutritional quality of wheat due to the presence of heavy metal and toxic elements (Srinivas et al. 2014; Lu et al. 2015; Anwar et al. 2016; Khan et al. 2017). Therefore, further studies for impact of waste water on nutritional quality and uptake of toxic elements should be conducted for formulation of any policy regarding the use of waste water for food crops especially wheat in the arid regions of the world.

There existed a strong co-relation of fertile tillers and grains per spike with the grain yield of wheat. Indeed, the fertile
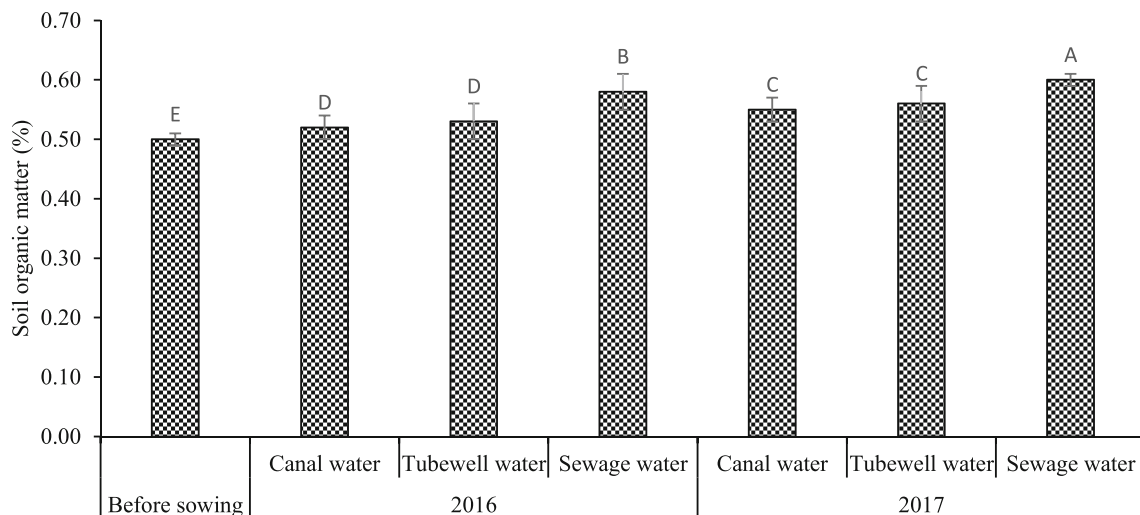

Fig. 3 Influence of water sources on the soil organic matter contents before sowing and after the harvest of experiment during both experimental years
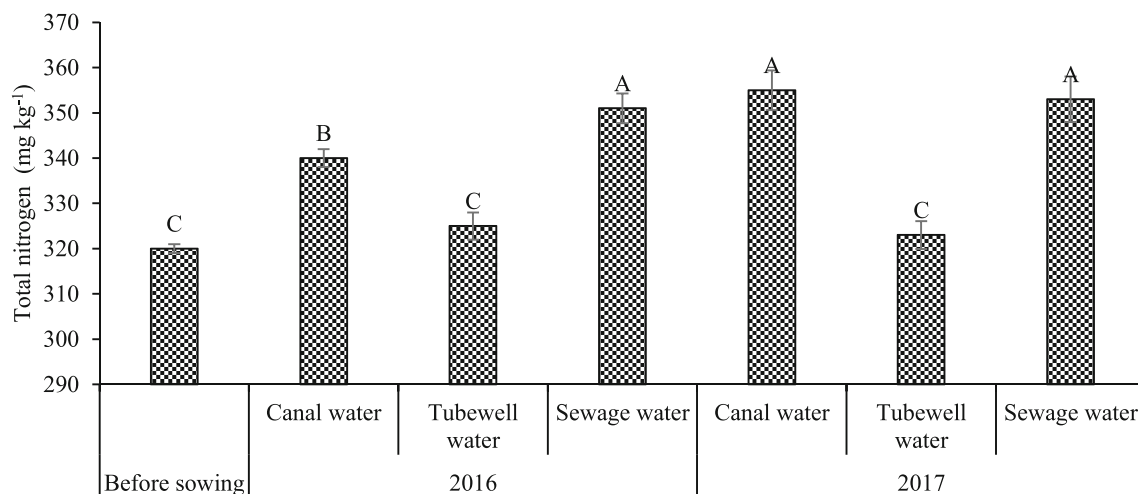
Fig. 4 Influence of water sources on the total nitrogen before sowing and after the harvest of experiment during both experimental years

tillers and grains per spike are two important yield contributing parameters and an increment in these parameters due to imposition of experimental treatments has been reported to increase the grain yield of wheat (Farooq and Nawaz 2014; Nawaz et al. 2016; Nawaz et al. 2017a &b; Ul-Allah et al. 2018). In this study, the grain yield was the highest in newly breed wheat cultivars (e.g., Gold-2016, Ujala-2016) than the older ones' wheat cultivars (e.g., Sehar-2006 and Lasani-2008). This indicated that the newly breed wheat cultivars of bread wheat have greater adaptability to the arid regions of Punjab, Pakistan, and their sowing is recommended in the arid areas to harvest the highest wheat yields.

The temperature and rainfall pattern remained similar for both years due to which the crop performance during both years was the outcome of the experimental treatments, and the year effect was found non-significant; thus, the data were pooled for both years (Tables 4 and 5). Likewise, there was continuous buildup of nitrogen, phosphorus, potassium, and soil organic matter in the experimental soil with passage of time (Figs. 3, 4, 5, and 6) which might be attributed to the

presence of the surplus amount of these nutrients in sewage water (Singh and Agrawal 2008; Srinivas et al. 2014; Anwar et al. 2016; Galal and Shehata 2015) and canal water which were used as experimental material for irrigation purposes during both years. The highest soil organic matter in sewage water–treated plots might be due to higher deposition of wheat straw and better root biomass which was retained in the soil and thus enhanced the soil organic matter. The sewage water also carried small organic materials which when improve the soil organic matter (Kirchmann et al. 2017). Usually, the total nitrogen is not higher in canal irrigated water in Pakistan. However, in this study, the total nitrogen was significantly higher in canal water during the second year which seems to be the result of runoff from some watershed area of Indus river of Pakistan which is extensively used for the production of maize crop—a heavily fertilized crop. The application of sewage water and canal water significantly enhanced the soil extractable potassium during both years of experiment than the tube well water (Fig. 5). Indeed, the soils of Pakistan have the dominance of mica type of minerals which are rich in
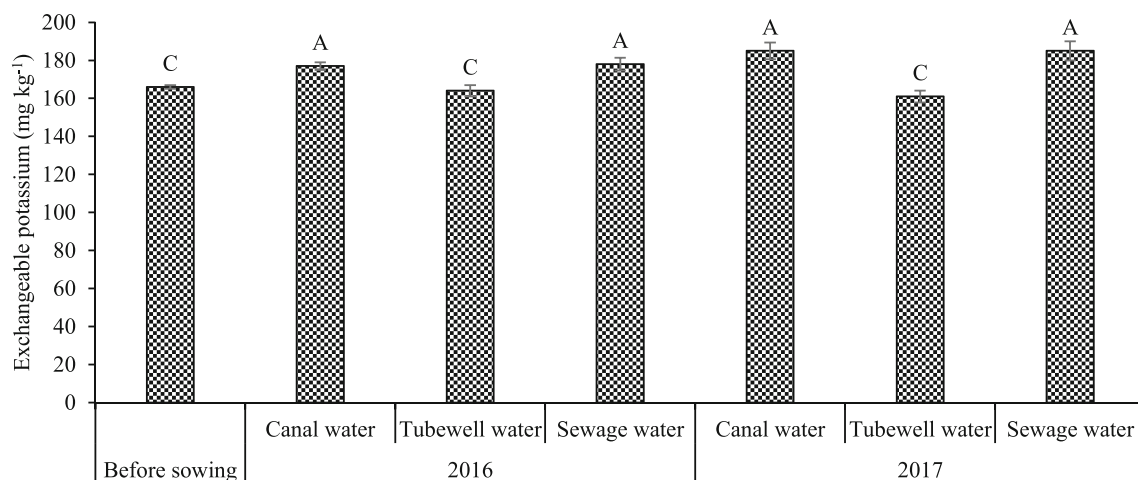

Fig. 5 Influence of water sources on the exchangeable potassium before sowing and after the harvest of experiment during both experimental years
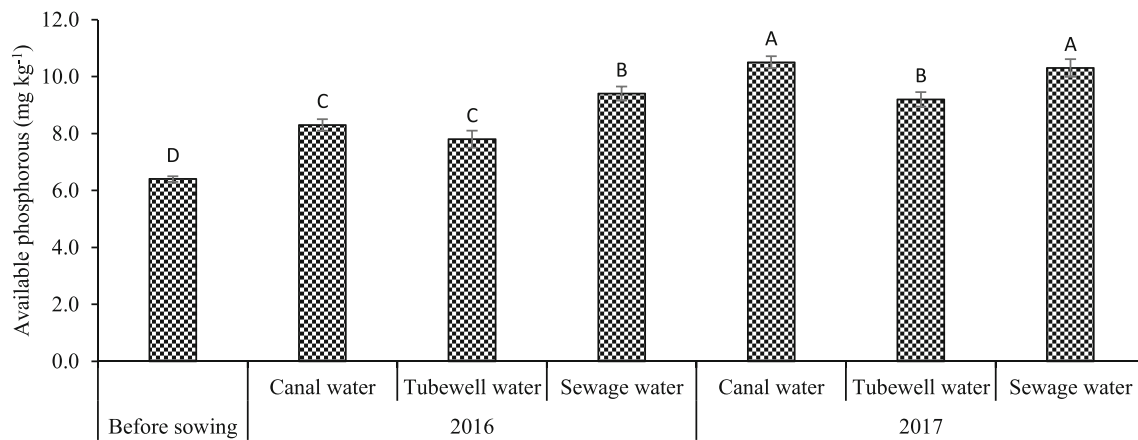
Fig. 6 Influence of water sources on the available phosphorus before sowing and after the harvest of experiment during both experimental years

potassium. Thus, the canal water of Pakistan have high amount of potassium. Likewise, the sewage water was brought from a long distance to the experimental field and it seems that the potassium in mica minerals at study was dissolved in sewage water due to which thee potassium contents were strikingly the same in canal and sewage water. The tube well water was brought to field from short distance with very little addition of potassium due to which the tube well water–treated plots have less soil potassium (Fig. 5). With the passage of time, improvement in soil organic matter due to the application of sewage water, canal water, and tube well water was the outcome of deposition of crop residues and the wheat roots in the rhizosphere which enhanced the soil organic matter pool in the experimental soil which was not under crop cultivation prior to experimentation.

Conclusion

The use of sewage water improved the performance of different wheat cultivars followed by irrigation with canal water against the tube well water which was attributed to build up of macronutrients (total nitrogen, available phosphorus, and extractable potassium) and improvement in the soil organic matter in the experimental soil. The improvement in wheat performance was visible through improvement in the fertile tillers, 1000-grain weight, and grains per spike. Thus, the sewage water might be used as an alternate source of irrigation in those arid lands where the canal and underground water is not available for irrigation purposes. However, sometimes, the sewage water may carry some toxic heavy metals whose accumulation in soil and translocation to wheat grains needs to be investigated in future long-term studies under arid climates to avoid any health risk, as wheat is staple of many people across the globe including Pakistan.

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