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Original article

Assessment of wheat productivity responses and soil health dynamics under brackish ground water

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A B S T R A C T

The continuous use of brackish groundwater for irrigation is detrimental for soil and crop attributes. A three-year research study was designed for the wheat crop to assess the effects of brackish groundwater on crop yield and soil health under a surface irrigation system. Three sites were selected in different cropping zones of Pakistan. The treatments comprised of irrigation with moderately brackish water having 0.8, 1.3 & 2.7 dSm^{-1} of salinity and canal water. The results indicated that EC, SAR, bicarbonates, Ca^{2+} and Mg^{2+} levels increased in the soil for consecutive years and this increase was more at site S3 followed by S2 and S1. As soil depth is concerned, the increase was more pronounced in upper layers of soil (0–15 cm) as compared to 15–30 cm depth. Growth and yield were also affected by the consecutive use of this water, the number of plants, plant height, the number of spikes per plant, and yield was reduced at all the three sites. However, the impact was less pronounced at the site S1 whereas S3 was the most affected one. Grain weight and dry matter weight were observed to be maximum at S1. Water productivity was also calculated for all the three sites. Maximum water productivity was observed at S1 followed by S2 & S3. It was concluded that the continuous use of brackish water would have an adverse effect on crop yield and subsequently, soil health is also affected by it significantly.

1. Introduction

Groundwater is considered as a supplemental source for irrigation and is exclusively used for irrigating crops especially in arid and semi-arid areas (Salehi et al., 2018). The easy availability of groundwater has encouraged farmers to use it as a supplement source of irrigation as >40% of the irrigation water requirements in Pakistan are met through groundwater (Cheema et al., 2014). It is primarily used for drinking purposes as 65% of the global population uses it for drinking purposes, 20% of it is used for irrigation and 15% is utilized by the industrial sector (Adimalla et al., 2018). However, the availability of freshwater for irrigation is a limiting factor worldwide (Saraiva et al., 2020). Irrigated agriculture is the mainstay of Pakistan's economy contributing about 21% of the gross domestic product (Shafique, 2017). However, even in the irrigated areas, the available water supply during certain times of the year is less than the consumptive use requirements for the crops (Hasan et al., 2019). Moreover, the erratic flow of water in rivers causes irregular surface water supply in the canal network and finally results in low crop yield per unit area (Aslam, 2016).

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Therefore, to meet the global challenge of food security and surface water shortages, irrigated areas are becoming more dependent on groundwater (Qureshi, 2015).

The easy accessibility of groundwater is not only causing the mining of aquifer (Butler Jr et al., 2018) but also resulting in secondary soil salinization (Qureshi, 2015). The quality of groundwater in the irrigated areas of Pakistan varies widely in space and depth and is linked to the reasons for the movement of groundwater in the aquifer (Awais et al., 2017). This water is considered as one of the major causes of salinity in the irrigated areas and resulted in low food productivity (Imran et al., 2018). The major problem with the continuous use of brackish groundwater is salinity built up in the soils which have detrimental effects on crop yield (Rengasamy, 2010; Wang et al., 2015). However, it can be used with proper crop management practices and irrigation scheduling (Tahtouh et al., 2019) for some plants such as wheat, maize and sunflower which are more tolerant to salinity. Therefore the use of brackish groundwater for these crops is more prevalent as compared to other crops (Feng et al., 2017). For the areas where the use of brackish water is unavoidable for irrigation, it is preferred that it should be applied at the later stages of crop development rather than using it during the early growth stages of the crop (Yuan et al., 2019) because of the sensitiveness of young plants towards salinity(Islam et al., 2019). Moreover delayed application of saline water would also increase the germination rate and lower the chances of salinity buildup in the root zone significantly. (Pang et al., 2010). However, the continuous use of brackish groundwater even delayed can also cause a reduction in crop yields and destroy soil health (Wang et al., 2009a).

Winter wheat (*Triticum aestivum* L) is among the major crops of southeast Asian countries like China, India, and Pakistan (Siah and Quail 2018). In Pakistan, wheat is cultivated on a large area and is one of the major cereal crops but its yield is highly dependent on irrigation water quality (Afzal et al., 2005; Pang et al., 2010; Wang et al., 2015). The most limiting factor for the winter wheat in these countries is the availability of fresh irrigation water (Sun et al., 2010; Xiao et al., 2013). The use of saline water becomes for irrigating crops and its impact on soil health as well as crop yield requires detailed investigation mostly with respect to soil salinization. Many researchers have attempted to investigate these impacts while employing pot or field experiments (Ahmad et al., 2007; Chauhan et al., 2008; Jiang et al., 2012; Murtaza et al., 2006; Pang et al., 2010; Singh et al., 2009; Wang et al., 2007; Wang et al., 2009b). This study aimed at assessing the harmful effects of saline water application on crop yield and water consumption, rather than its impacts on soil salinity. Therefore, the objectives of study were to demonstrate the soil salinity distribution under different soil depths and evaluation of grain yield, water productivity, and harvest index of winter wheat under different irrigation water qualities.

2. Materials and methods

2.1. Study area

The research study was conducted in the Punjab province of Pakistan. To execute the study, three different sites Madhrianwala (S1), Village No. 29 N (S2), and Village No. 123 GB (S3) were selected as depicted in Fig. 1 and Table 1. The site selection was done before the initiation of the study during the first year on the basis of groundwater quality. S1 exists in Rice-Wheat cropping zone, whereas, S2 and S3 lies in the mixed cropping zone. The field experiments were laid on Winter Wheat for the cropping seasons 2015–16, 2016–17, and 2017–18.

2.2. Climate and soils

The climate of the study area was hot and dry during the summer and moderately cold in winter. The average maximum summer temperature in June is 48 °C while in winters during January the lowest minimum average temp is 7 °C (PMD, 2015). Owing to the proximity of the hills, there is more rainfall in the East than in the West. The majority of the rainfall occurs during the monsoon season with some scattered rainfalls in winter also. The monsoon season usually starts in the middle of July and continues until September and the average annual precipitation is 445 mm (Usman et al., 2015). The soils of the area were alluvial and fertile with generally flat topography and varying organic matter. Mainly the soils were dominated by medium to fine sands and silt, though clay particles were prominent in depressions (Rehman et al., 1997).

2.3. Experimental design and field trials

The research trials were conducted during the months (Nov-April) 2015–16, 2016–17, and 2017–18 on Winter Wheat crops at described locations. The comprehensive monitoring of the crop was done throughout the cropping season. The experiment was laid down under a split-plot under randomized complete block design (RCBD) arrangement with three replicates. Each replicate was taken as a farmer field of one acre at all sites. All the management practices are described in Table 2.

2.4. Soil sampling and analysis

Five soil samples were collected from each experimental site at depth (i.e. 0–15 cm and 15–30 cm) before sowing and after harvest. The soil samples were air-dried for 1–2 days and sieved with a 2 mm sieve. Soil pH and EC was determined by pH and EC meter. Carbonates (CO_3^-) and bicarbonates were determined by titrating against (N/10) sulfuric acid (H_2SO_4) using phenolphthalein as an indicator in carbonates and methyl orange in bicarbonates. Ca^{2+} + Mg^{2+} in soil was determined by titrating against 0.01 N versinate (EDTA) solution using erio-chrome black T indicator in presence of a buffer solution. Sodium (Na^+) was determined by a flame photometer. Analytical methods of Handbook 60 of USDA were used for different determinations (Allison and Richards, 1954).

2.4.1. Sodium adsorption ratio (SAR)

SAR was calculated by the formula given by (Richards, 1954):

$$SAR = \frac{Na}{\sqrt{\frac{Ca+Mg}{2}}} \quad (1)$$

All units are in meL^{-1}

2.5. Water analysis

To record the impact of brackish groundwater on soil and crop health water samples in the study area from the tubewells were also collected along with the soil samples and analyzed in the lab. In addition to above-mentioned parameters i.e EC & SAR for soil RSC of irrigation water was also determined as follows.

2.5.1. Residual sodium carbonate (RSC)

RSC was calculated by using the following relationship (Richards, 1954)

$$RSC\left(meL^{-1}\right) = (CO_3^- + HCO_3^-) - (Ca^{++} + Mg^{++}) \quad (2)$$

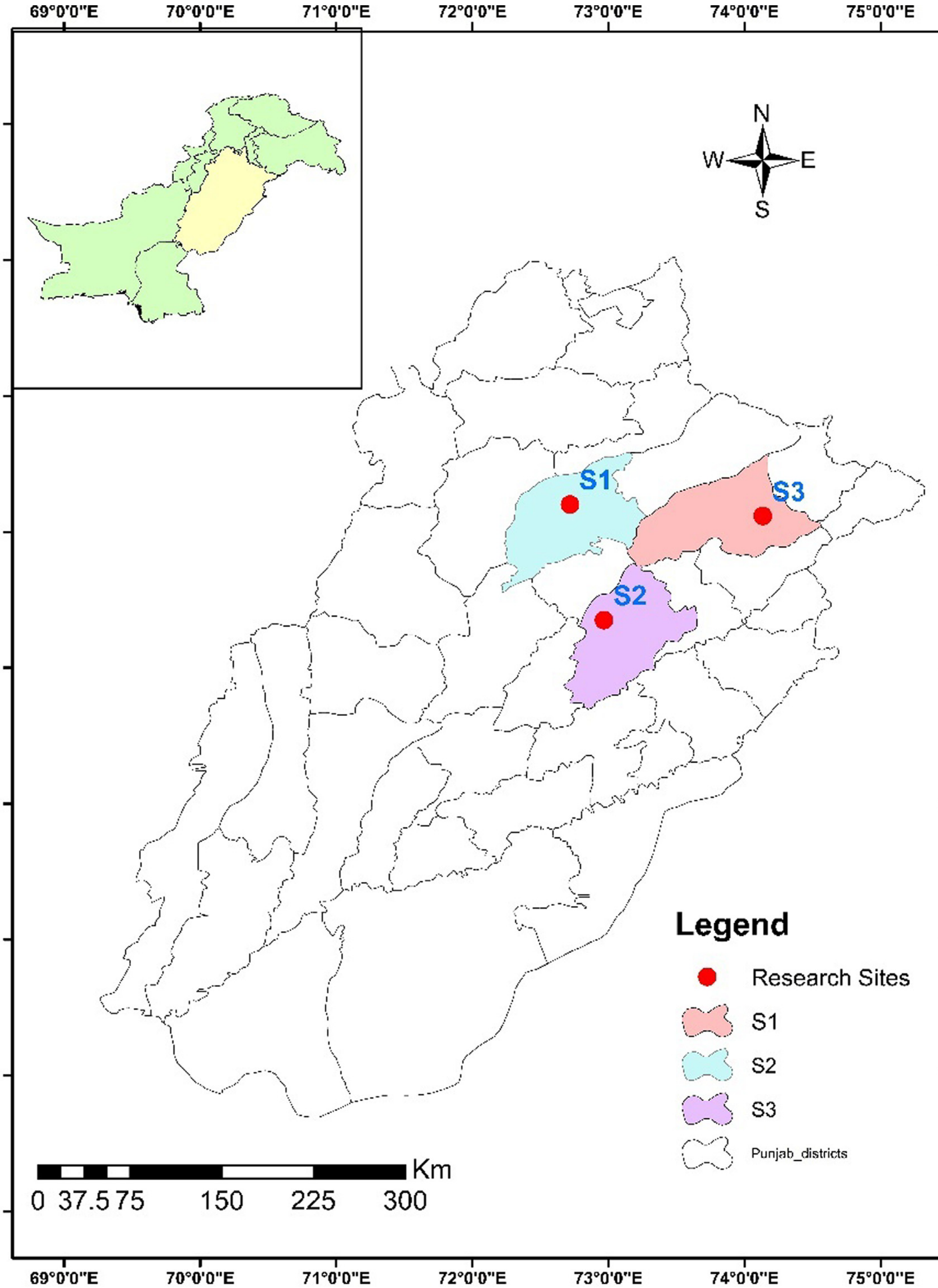

Fig. 1. Location map of Punjab, Pakistan showing the research sites (S1, S2, S3).

Table 1
Longitudinal and latitudinal features of the research sites.

Sr. No.	Location name	Symbology	Latitude	Longitude
1	Madhrianwala	S1	32° 12′ N	72°43′ E
2	Village No. 29	S2	31°21′ N	72°58′ E
3	Village No. 123	S3	32°07′ N	73°68′ E

Table 2
Description of crop management practices i.e. fertilizer applied, irrigation schedule, type of irrigation, sowing and harvesting date at research sites.

Sr. No.	Activity	Description
1	Field size	1 Acre
2	Crop variety	Galaxy-2013
3	Date of Sowing	22-11-2017
4	Information about any disease/pest attack	Nil
5	Pesticides and weedicides details	Buctrilsaper 300 ml/Hec, Axil 330 ml/ Hec
6	Quantity of seed per acre	50 Kg
7	Row spacing	25 cm
8	Schedule and quantity of supplied dose of Fertilize	1 bag Potash, 2 bag DAP at sowing, 2 bag Urea during 1st and 2nd irrigation.
9	Type of irrigation	Flood irrigation
10	Irrigation schedule	20–12-2017 (First irrigation) 10–01-2018 (Second irrigation) 10–02-2018 (Third irrigation) 02–03-2018(Fourth irrigation) 18–03-2018(Fifth irrigation)
11	Heat units consumed from sowing to full maturity	1815
12	Total days taken by the crop from sowing to full maturity	155
13	Date of harvesting	26–04-2018
14	Actual/ Potential yield	1800/2400 kg /acre

The tubewells which were used to irrigate the fields were selected for the sampling purpose and tubewell specifications of each site is presented in Table 3.

2.6. Water productivity

For the groundwater irrigation purpose, the discharge was measured by the trajectory method and for the canal, irrigation discharge was measured using a cut-throat flume of size (7. 5 $\times$ 20 cm). The discharge measured was then multiplied by the time of irrigation to calculate the actual volume of water applied per irrigation which was further converted to the total volume applied by adding the number of irrigations. The volume of water applied was then divided with the area irrigated to obtain the depth of water applied. Finally, the water productivity was calculated by dividing the crop yield (kg) with the volume of water applied (m^3) using the following relationship

$$WP = \frac{\mathrm{GrainorSeedYield}}{\mathrm{Waterappliedtothefield}} \mathrm{kgm} - 3 \quad (3)$$

2.7. Harvest index

The harvest index actually represents the efficiency of the system to convert dry matter weight into grain yield (Dai et al., 2016). The harvest index for the wheat crop was calculated using the following Eq. (4).

$$HI = \frac{Grainyield(kg/ha)}{Drymatterweight(\frac{kg}{ha})} \quad (4)$$

2.8. Statistics

The data were analyzed by using analysis of variance (ANOVA) and mean values were compared by least significant difference (LSD) at 0.05 level. The'Statistix 8.1′ statistical software was utilized for this purpose. Pearson correlation was determined by using XLSTAT software.

3. Results

3.1. Irrigation water quality

The quality parameters of canal water (CW) and brackish water (BW) for all sites were measured every year before the trial. The water of the S1 was found unfit for irrigation as the mean value of RSC was calculated as 5.58 meL^{-1} for all three years, whereas, EC and SAR mean values were found to be in permissible limits i.e. 1.26 dS/m and 6.45 respectively as depicted in Table 4. The values were compared with the standards given by WAPDA (Water and Power Development Authority), Pakistan for irrigation purposes. Similarly, the irrigation water of S2 was also fit in terms of EC & SAR, however, the RSC value was above the prescribed limits rendered it unfit for irrigation. The mean values of EC, SAR, and RSC were calculated as 0.89 dS/m, 2.12 and 9.03 meL^{-1} (Table 4). The quality of water at S3 was found worst among all three sites. The mean value of EC was 2.05 dS/m, SAR was 12.58 and RSC was 8.30 meL^{-1}.

3.2. Chemical properties of soil

Data regarding chemical properties of soil after irrigation with canal water (CW) and brackish water (BW) is presented in Tables 5–7. The Spatio-temporal variation in EC, SAR, Carbonates, Bicarbonates & Ca^{2+} + Mg^{2+} of all research sites was examined. The canal water was considered safe for irrigation and no significant change in soil chemical characteristics was observed for canal water irrigation. However, with the brackish water at S1, EC values increased for 0–15 cm, while no significant increase at 15–30 cm soil depth was noted (Table 5). A significant increase in SAR, Bicarbonates and Ca^{2+} + Mg^{2+} was observed for 0–15 cm soil depth whereas not much increase for the soil depth 0–30 cm was observed for all these parameters. Similarly, treatments did not affect carbonates for both the depths. For S2 no noticeable change was observed in all the soil chemical properties for canal irrigation for both the soil layers. Whereas Brackish water showed negative impact on almost all parameters except carbonates (Table 6). All the values of EC, SAR, Bicarbonates & Ca + Mg were observed to be increased in subsequent years. This increase was more prominent in first layer .i.e. 0–15 cm in comparison to second layer (15–30 cm). Similar kind of trend was observed for S3 where canal water usage had not shown any noticeable change in soil chemical characteristics. While the first layer (0–15 cm) was affected much with an increase in EC, SAR, Bicarbonates & Ca + Mg as compared with (15–30 cm) layer for brackish water usage (Table 7). Overall, soil chemical properties was more affected at S2 followed by S3 and S1.

Table 3
Specifications of Tubewells (discharge, depth, diameter, power source and type) at the research sites.

Location	Discharge (lps)	Depth (m)	Dia(cm)	Power source	Type of pump
S1	23.6	24.4	12.7	Diesel Engine	Centrifugal pump
S2	22.7	12.2	15.24	Diesel Engine	Centrifugal pump
S3	24.6	36.6	15.24	Diesel Engine	Centrifugal pump

Table 4
Values of electrical conductivity, sodium absorption ratio, residual sodium carbonates of irrigation water at all research sites in the growth seasons of 2015–16, 2016–17 and 2017–18.

Location	1st Year	2nd Year	3rd Year	1st Year	2nd Year	3rd Year	1st Year	2nd Year	3rd Year	**Remarks**
	EC (dS/m)			**SAR**			**RSC (meL^{-1})**			
S1	1.19	1.30	1.31	6.36	6.51	6.48	5.94	5.40	5.40	Unfit
S2	0.89	0.71	0.83	1.97	2.19	2.20	8.90	9.30	8.90	Unfit
S3	2.05	2.07	2.03	12.12	12.76	12.88	8.20	8.40	8.30	Unfit

Table 5
Changes in soil chemical properties at different soil depth i.e. 0–15 cm and 15–30 cm by irrigation with canal water and brackish water in the cropping seasons 2015–16, 2016–17 and 2017–18 at S1.

Soil Depth (cm)	1st Year	2nd Year	3rd Year	1st Year	2nd Year	3rd Year	1st Year	2nd Year	3rd Year	1st Year	2nd Year	3rd Year	1st Year	2nd Year	3rd Year
	EC(dS/m)			**SAR**			**Carbonates**			**Bicarbonates**			**Ca^{++}+Mg^{++}**		
Canal Water (0–15)	1.38	1.39	1.38	4.5	4.42	4.54	0	0	0	5.01	4.95	5.1	15	14.5	15.5
Canal Water (15–30)	1.56	1.57	1.56	4.95	4.90	4.96	0	0	0	5.5	5.45	5.40	17	16	17.5
Brackish Water (0–15)	1.98	2.06	2.18	5.12	6.61	6.50	0	0	0	7.4	8	9.8	28	29	33
Brackish Water (15–30)	1.57	1.60	1.63	5.00	5.25	5.32	0	0	0	5.7	6	6.21	18	28	30

Table 6
Effect of irrigation with canal water and brackish water on soil chemical properties at different depths i.e. 0–15 cm and 15–30 cm in cropping season 2015–16, 2016–17 and 2017–18 at S2.

Soil Depth (cm)	1st Year	2nd Year	3rd Year	1st Year	2nd Year	3rd Year	1st Year	2nd Year	3rd Year	1st Year	2nd Year	3rd Year	1st Year	2nd Year	3rd Year
	EC(dS/m)			**SAR**			**Carbonates**			**Bicarbonates**	**Ca^{++}+Mg^{++}**				
Canal Water (0–15)	1.40	1.41	1.40	4.7	4.75	4.54	0	0	0	5.12	5.01	5.1	16	14.1	16.1
Canal Water (15–30)	1.57	1.59	1.58	4.86	4.89	4.90	0	0	0	5.7	5.78	5.55	18	15	16.5
Brackish Water (0–15)	2.19	2.29	3.92	6.25	7.5	7.8	0	0	0	9.4	10	12	30	32.5	35.3
Brackish Water (15–30)	2.07	2.2	1.55	5.83	6.3	6.5	0	0	0	9.2	9.8	10.8	28	30.2	31.2

Table 7
Effect of irrigation with canal water and brackish water on soil chemical properties at different depths i.e. 0–15 cm and 15–30 cm in cropping seasons 2015–16, 2016–17 and 2017–18 at S3.

Soil Depth (cm)	1st Year	2nd Year	3rd Year	1st Year	2nd Year	3rd Year	1st Year	2nd Year	3rd Year	1st Year	2nd Year	3rd Year	1st Year	2nd Year	3rd Year
	EC (dS/m)			**SAR**			**Carbonates**			**Bicarbonates**			**Ca^{++}+ Mg^{++}**		
Canal Water (0–15)	1.39	1.38	1.39	4.65	4.67	4.74	0	0	0	5.31	5.95	5.5	17	16.89	16.5
Canal Water (15–30)	1.56	1.56	1.57	4.75	4.88	4.89	0	0	0	5.8	6.01	5.8	17 0.5	16	17.5
Brackish Water (0–15)	2.98	3.06	3.98	7.12	7.61	7.8	0	0	0	10.4	11	12.8	32	33.5	35.75
Brackish Water (15–30)	2.57	2.60	2.64	6.01	6.25	6.32	0	0	0	9.7	9.8	8.21	30.5	30.25	31.25

3.3. Plant growth and yield

Data about plant growth and yield parameters of S1 after irrigation with canal and brackish water is presented in Fig. 2. There was significant ($p \leq 0.001$) effect on number of plants by canal water (CW) and brackish water (BW) irrigation. The reduction was more with BW treatment in 2016–17 and 2017–18. Plant height was significantly ($p \leq 0.001$) affected by CW and BW treatments during all years. Maximum plant height was observed with CW treatment in 2016–17 and minimum plant height was observed in 2017–18 with BW treatment. Number of spikes/plant was also significantly ($p \leq 0.001$) affected by both treatments. Maximum spikes were recorded with CW treatment in all years, while minimum was observed in 2017–18 with BW treatment. Treatments had significant ($p \leq 0.001$) effect on crop yield. Highest increase was noted with CW treatment while lowest was observed with BW treatment in 2017–18.

The effect of canal water and brackish water treatments for the S2 is depicted in Fig. 3. The number of plants were significantly ($p \leq 0.001$) affected by both treatments. There was not remarkable increase in plant height by CW treatment in three years, while maximum reduction was observed in 2017–18 by BW treatment. Similarly, a significant ($p \leq 0.05$) effect on plant height was noticed and highest reduction in plant height was observed in 2017–18 by continuous application of brackish water. Brackish water showed highly significant ($p \leq 0.001$) effect on number of spikes during all years. CW treatment showed a constant effect on number of spikes. BW treatment depicted highest reduction in number of spikes in 2017–18. The yield was also significantly ($p \leq 0.001$) affected by both treatments. It was gradually decreased by BW treatment with maximum in 2015–16 followed by 2016–17 and 2017–18.

At S3, brackish water irrigation also had a negative impact on wheat growth and yield as shown in Fig. 4. Treatments had

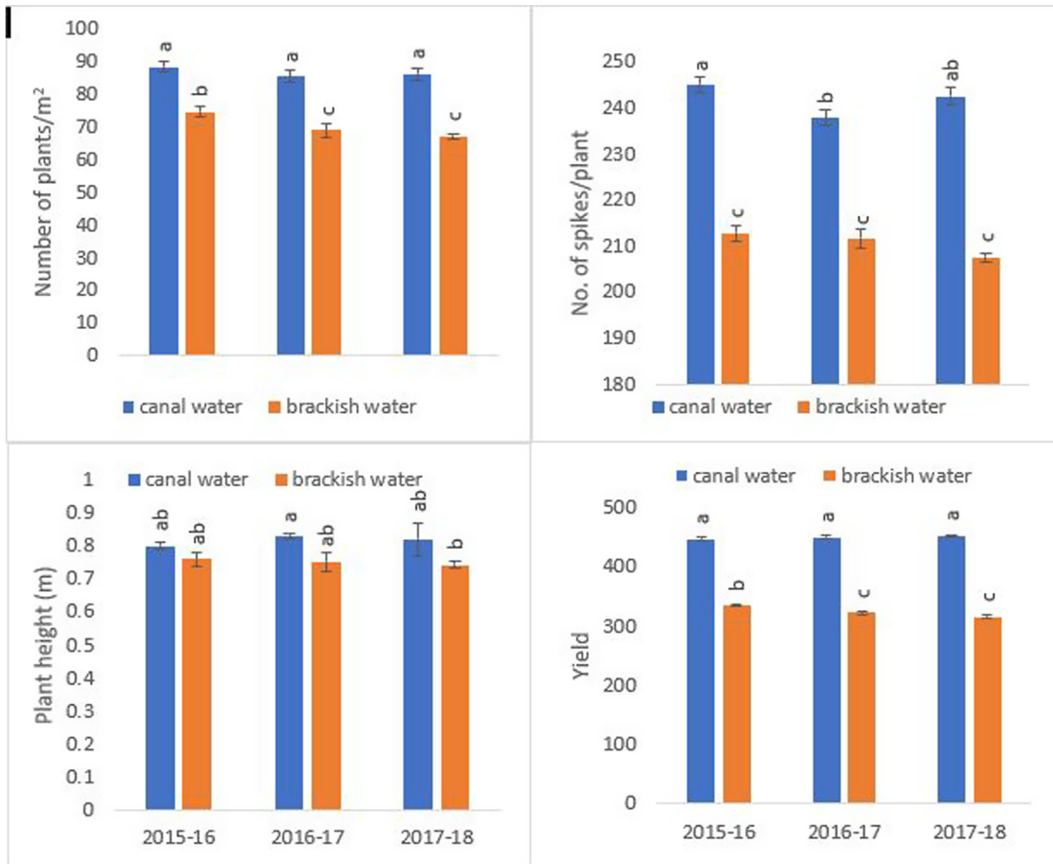

Fig. 2. Number of plants, plant height, number of spikes, and yield of wheat at S1 after irrigation with canal water and brackish water in the cropping seasons 2015–16, 2016–17 and 2017–18. Values are means of three replicates (n = 3). Different letter(s) exhibit significant difference among means (P > 0.05).

significant ($p \leq 0.001$) effect on number of plants. BW treatment exhibited reduction in plant height with minimum in 2017–18. Treatments also showed highly significant ($p \leq 0.001$) effect on plant height, number of spikes/plant and yield. The effect was more pronounced in the year 2017–18.

3.4. Crop yield attributes

Grain weight and dry matter weight data for all three sites are represented by Table 8. The results showed that grain and dry matter weight was significantly ($p \leq 0.001$) affected by CW and BW treatments. The BW had more effect as compared to CW. Maximum yield was observed in S1 followed by S3 and S2.

3.5. Water productivity

Water productivity shows the ability of an agricultural system to convert water into food. Water productivity was calculated for both the treatments by utilizing the data of water applied throughout the whole cropping season and yield obtained under each treatment. The results are summarized in Table 9 which shows that water productivity of S1 was observed to be maximum among all the three sites as it was 0.974 with canal water and 0.796 with brackish water while it reduced subsequently at the other two sites. It was calculated as 0.955 and 0.74 for S2 and S3 respectively using canal water and 0.77 and 0.60 using the brackish water for both the sites.

3.6. Harvest index

The effects of brackish water application and good quality canal water application on harvest indices of wheat crop were statistically examined and mentioned in (Table 10). The HI reduced in an order S1 < S2 < S3. A harvest index of 0.75 was observed for canal water and wheat irrigated with brackish water produced comparatively less harvest index i.e. 0.54 for the S1. Similarly, S2 & S3 showed the HI of 0.75 and 0.69 with the canal water application while the value was noticeably reduced to 0.62 and 0.68 in the case of brackish water application respectively. These findings revealed that irrigation with poor quality water affected the harvest index.

3.7. Correlation analysis

Pearson correlation analysis was performed to study the relationship among brackish water and wheat productivity. It indicated that quality parameters of brackish water i.e. EC, SAR and RSC are negatively correlated with growth (number of plants/m^2 and plant height) and yield (spikes/plant, grain weight, dry matter weight, water productivity and harvest index) attributes, while all these growth and yield parameters are positively correlated with each other (Fig. 5). This depicted the close relationship between brackish water and wheat growth attributes.

4. Discussion

Irrigation of crops with brackish water is directly linked with increasing damage to soil health and loss in crop productivity. As

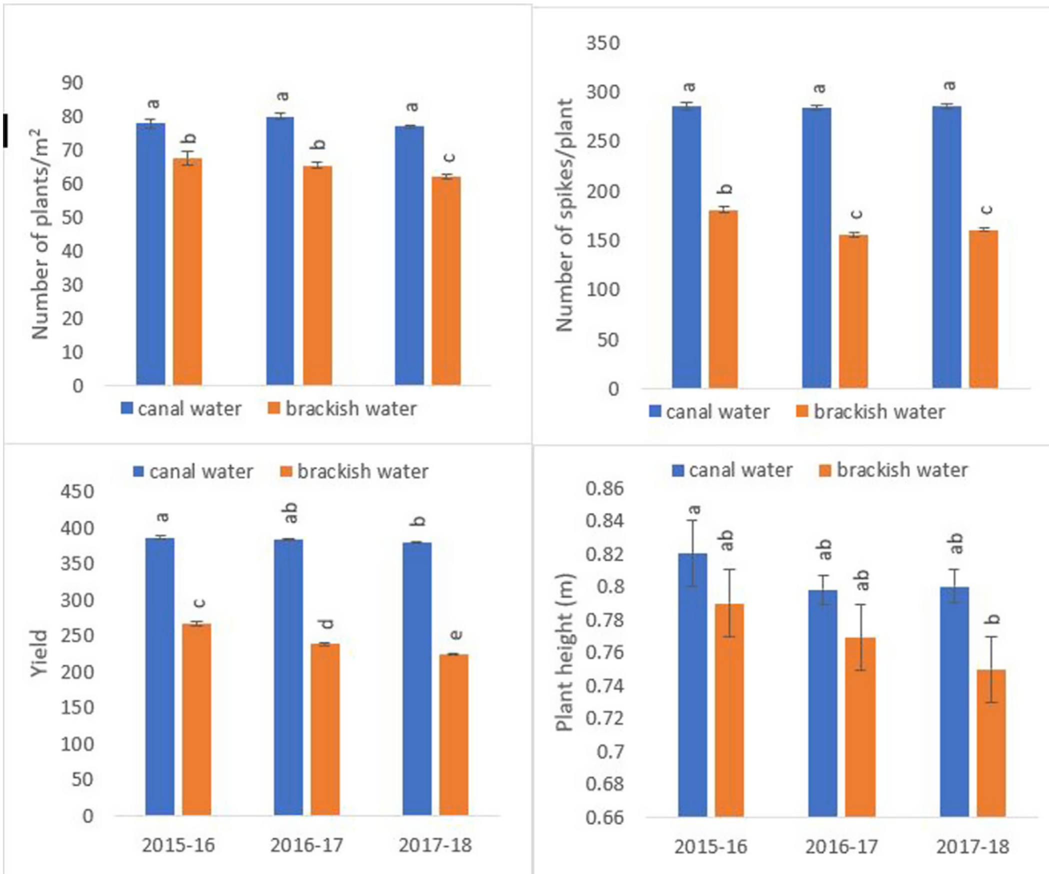

Fig. 3. Effect of irrigation with canal water and brackish water on number of plants, plant height, number of spike and yield of wheat in cropping seasons 2015–16, 2016–17 and 2017–18 at S2. Values are means of three replicates (n = 3). Different letter(s) exhibit significant difference among means ($P > 0.05$).

continuous use of this water worsen the physical and chemical characteristics of soil with a subsequent decline in plant growth and yield (Abdelhafez et al., 2020; Rashash Ali et al., 2015; Ravikumar et al., 2011; Singh 2020). Hence, efforts are being carried out to achieve goal of sustainable agricultural development by managing use of brackish water and its influence on soil quality (He et al., 2017). In the current study, we have found the difference in quality of irrigation water collected from three agricultural sites. The change in chemical and physical properties of collected irrigation water from all sites indicates level of suitability and associated limitations on crop growth and yield. This crux is supported by the earlier studies and indicates that long term irrigation may cause soil salinity and degradation which ultimately have a negative impact on crop yield (Hammam and Mohamed 2020; Singh 2020).

Water contains several alkaline and non-alkaline earth ions e.g. (Ca^{2+}+Mg^{2+}, Bicarbonates) when the concentration of alkaline earth metals increases consequently RSC also increases (Ravikumar et al., 2011; Sundaray et al., 2009). A high RSC value is considered harmful for soils (Zaman et al., 2018). In the current study, continuous irrigation with brackish water for three years increase bicaronates and Ca^{2+} + Mg^{2+} concentration and their high values were observed at S3 followed by S2 and S1. In fact, these two attributes contributed in compromised quality and highlights a gradual degradation and non-suitability of irrigation water. Such increase in values e.g. RSC, Ca^{2+} is correlated with other soil problems based upon irrigation with brackish quality (El-Sayed et al., 2012). For instance, an increase in sodium concentration is observed in soils subjected to irrigation with high RSC (Riaz et al., 2018) thereby, decreasing the quality of irrigation water. The presence of excessive ions not only cause toxicity in plants but can also alter the soil structure and properties (Yadav and Kumar 2019). In addition to this, the soil salinity decreased with soil depth. Salt accumulation was more in 0–15 cm depth as compared to 15–30 cm and this trend was same at all sites. Earlier investigations have shown a positive correlation between groundwater depth and salinity. This is because of the increased rate of evaporation that also increase salt concentration in upper layers of soil (Dou et al., 2019; Liu et al., 2016). (Chauhan et al., 2008) also observed the similar results in their experiment with the lowest salinity at the depth of 60–90 cm. Our results are also parallel with (Sharma et al., 2001) and (Verma et al., 2012).

Similarly, rise in soil EC and SAR due to continuous irrigation with brackish water ultimately degrade physical and chemical attributes of soil (Abd-Elmabod et al., 2010; Hendawy et al., 2019; Iqbal et al., 2014). We observed that irrigation with brackish water increased soil EC, SAR and it was more at S3 then S2 and S1, which is evidenced by enhanced accumulation of soluble salts and sodium ions. The reason behind low crop growth and productivity due to brackish water is actually such increase in salinity and SAR values. These two parameters particularly cause problems such as crust development, poor drainage, low tilth (Abbas et al., 2019; Abdelhafez et al., 2020; Cerdà et al., 2020; Ullah et al., 2020). Such problems due to salinity, directly results in hazardous effects on plant physiology, biochemistry and yield (Akhter et al., 2021). Cumulatively, they endanger the survival of plants and only plant species that are well able to cope these hazards can survive. Our recorded decline in plant attributes due to quality of water is positively correlated with attributes of water. In our study, the use of brackish water for three consecutive years declined crop vigor and

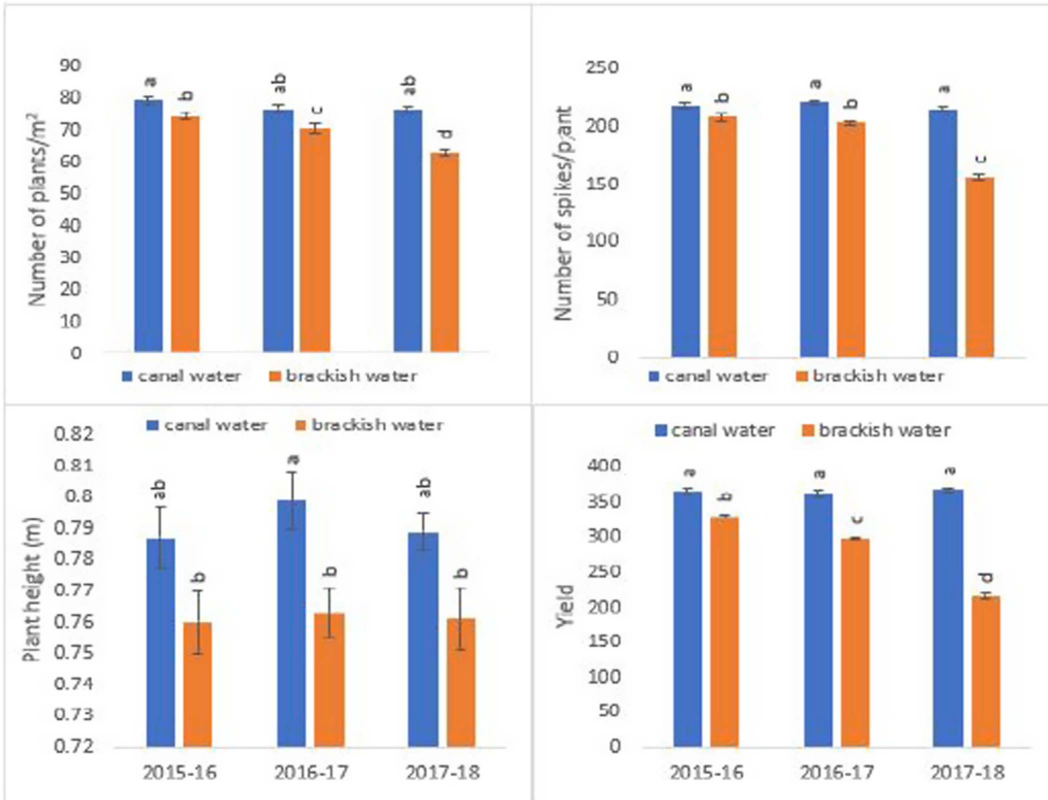

Fig. 4. Changes in number of plants, plant height, number of spike and yield of wheat by irrigation with canal water and brackish water in the cropping seasons 2015–16, 2016–17 and 2017–18 at S3. Values are means of three replicates (n = 3). Different letter(s) exhibit significant difference among means (P > 0.05).

Table 8
Grain weight and dry matter weight of wheat by irrigation with canal water and brackish water at research sites of year 2017–18. Values are means of three replicates (n = 3).Each column followed by the same letter(s) are not significantly different according to LSD at 0.05 probability.

Location	Treatment	Grains weight (g/m^2)	Dry matter weight (g/m^2)
S1	Canal water	346.6 ± 1.43^a	469.2 ± 1.91^a
	Brackish water	303.9 ± 1.09^b	431.8 ± 1.86^b
S2	Canal water	268 ± 1.09^a	413 ± 1.86^a
	Brackish water	234.8 ± 1.64^c	377.2 ± 1.58^c
S3	Canal water	318 ± 1.78^a	447 ± 2.10^a
	Brackish water	294.1 ± 1.79^d	423.6 ± 2.14^d

yield. Such depression in wheat growth can be significantly because of high Na^+, osmotic changes in soil and low mineral nutrient uptake from soil (Arzani 2008). Subsequent reduction in plant height is advocated by the absorption of salt by roots and its transport to leaves which affect the crop growth to various degrees (Ben-Asher et al., 2006). Besides, duration of irrigation was also the main aspect for salt accumulation in the soil, and the continuous irrigation with brackish water for one year increased salt concentration (Liu et al., 2019). A reduction in wheat yield due to irrigation with saline water has been recorded by many scientists (Francois et al., 1994; Jiang et al., 2012; Soliman et al., 1994). Similar results are found in the present study. This might due to textural properties of soil which prevent leaching of salts and therefore salts remained in the root zone which reduced the yield (Rajpar and Wright 2000).

Our results depicted that brackish water irrigation decreased crop harvest index. Earlier studies reported that irrigation with saline water decreased water uptake, water loss, and CO_2 assimilation. Due to effect on these processes, plants productivity is affected (Hussain et al., 2016; Niu et al., 2012). For final year, the wheat yield followed the order S3 < S2 < S1.

5. Conclusion

Our results exhibit deteriorated t chemical properties of soil by increasing EC, SAR, Bicarbonates, and Ca^{2+} and Mg^{2+} due to continuous irrigation with brackish water This increase in soil attributes

Table 9
Water productivity (kg/m^3) and grain yield of wheat plants irrigated with Canal water and Brackish water of year 2017–18. Values are means of three replicates (n = 3).Each column followed by the same letter(s) are not significantly different according to LSD at 0.05 probability.

Location	Treatment	Total water depth applied (mm)	Volume of water used per hectare (m^3)	Grain yield (kg/ha)	Water productivity (kg/m^3)
S1	Canal water	464	4640	4472.6 ± 3.36^a	0.974 ± 0.02^a
	Brackish water	464	4640	3665.6 ± 2.16^b	0.796 ± 0.01^b
S2	Canal water	464	4640	4840.2 ± 1.24^a	0.955 ± 0.02^a
	Brackish Water	464	4640	3631.4 ± 1.5^c	0.772 ± 0.02^c
S3	Canal water	464	4640	3636.4 ± 3.18^a	0.74 ± 0.01^a
	Brackish Water	464	4640	2921.2 ± 2.2^d	0.60 ± 0.01^d

Table 10
Harvest Index of wheat after irrigation with canal water and brackish water of year 2017–18. Values are means of three replicates (n = 3).Each column followed by the same letter (s) are not significantly different according to LSD at 0.05 probability.

Station	Treatments	Yield (kg/ha)	Dry matter (kg/ha)	Harvest index (HI)
S1	Canal water	4472.6	5957	0.75 ± 0.02^{a}
	Brackish Water	3665.6	4855	0.54 ± 0.01^{b}
S2	Canal water	4840.2	6453	0.75 ± 0.02^{a}
	Brackish Water	3631.4	5854	0.62 ± 0.02^{c}
S3	Canal water	3636.4	5312	0.69 ± 0.01^{a}
	Brackish Water	2921.2	4356	0.68 ± 0.01^{d}

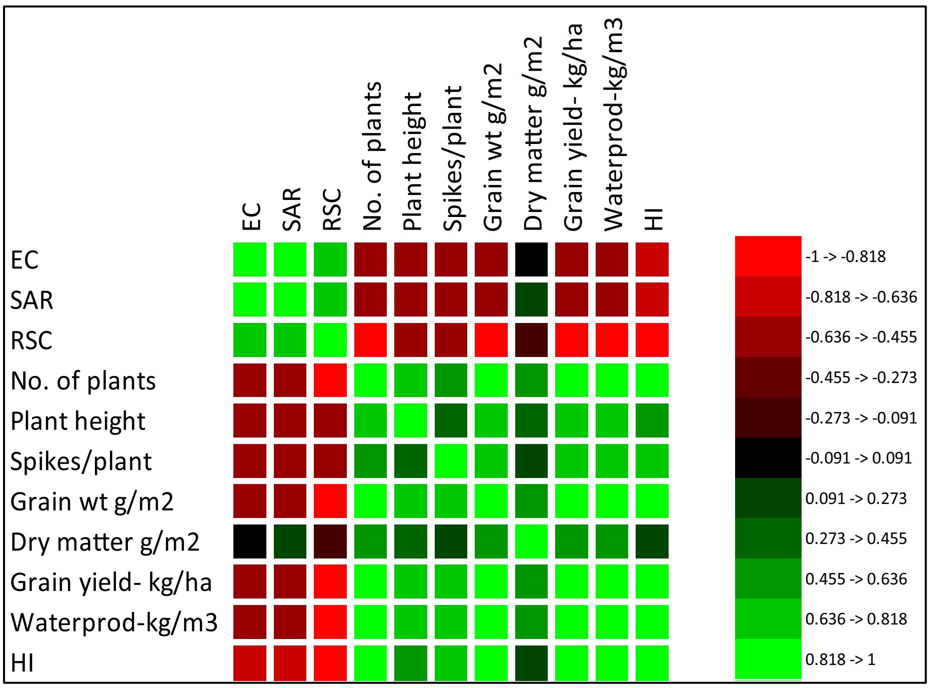

Fig. 5. Correlation matrix among water quality parameters on growth and yield parameters of wheat. EC: Electrical conductivity; SAR: sodium absorption ratio; RSC: Residual sodium carbonate; HI: harvest index.

i.e. RSC, SAR, Ions was more pronounced in the upper layers of the soil (0–15 cm). Such changes adversly affected wheat growth and reproductive parameters. The number of plants and plant height was declined during the first year with brackish water irrigation and this effect increased in the subsequent years. All yield parameters were also influenced by brackish water irrigation in all years as compared to control. Soil health, growth, and yield parameters were least affected at S1 site, then S2 and S3. It is therefore recommended that continuous use of brackish water may be harmful to soil health and crop productivity simultaneously and should be avoided to have higher crop yields.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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