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Quality Assessment of Tubewell Water for Irrigation and Impact on Soil and Crops in Central Punjab, Pakistan

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Authors' contributions

This work was carried out in collaboration between all authors. Author MI designed the study, wrote the protocol and the first draft of the manuscript, and managed the literature searches. Author SJ managed the analyses of the study and performed the statistical analysis. All authors read and approved the final manuscript.

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ABSTRACT

Aims: The study was conducted to assess the quality of tubewell (TW) waters for irrigation and their effects on soils and crops.
Place and Duration of Study: Canal Command Area (CCA) of Chichawatni and Sahiwal tehsils of district Sahiwal, Punjab, Pakistan during 2012 and 2013.
Methodology: A total of 529 TW water samples were collected from nine distributaries of Lower Bari Doab Canal (LBDC); four on right side (RD); five on left side (LD).Twenty composite soil samples were collected at plough layer depth (0 to 15 cm) from the selected farmer fields irrigated with TW and canal water (CW). Soils were analysed for pHs, ECe, and water samples were analysed for EC, cations (Ca^{2+}+ Mg^{2+}, Na^{+}) and anions (CO_3^{2-}, HCO_3^{-}) and then RSC and SAR were computed. Total dissolved salts (TDS) of TW waters were used to estimate the amount of salts added into soil with the irrigation. The salts addition into soil under different crops was also

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calculated using the consumptive use by crops. The yield data of crops were recorded from 20 farmer's fields irrigated with CW and TW waters to evaluate the effects of water quality on the yields.

Results: Data based on EC, RSC and SAR values showed that 71% TW waters were saline and >20% samples were sodic in nature. The quality of TW water in RD was comparatively better than in LD due to its location between LBDC and Ravi River. The farmers used poor quality TW waters (TDS from 218 to 3309 mg L^{-1}) that added 0.66 to 10.05 t ha^{-1} salts into soil with 0.30 m irrigation water. Similarly, 15.75, 27.80, 33.36, 44.48 and 55.99 t ha^{-1} TDS were deposited in soil by wheat, cotton, potato, spring maize and rice, respectively, irrigated with TW water of TDS 3309 mg L^{-1}. The yields of crops reduced from 3 to 15% where usually TW water was used compared to CW irrigated fields.

Conclusion: Results showed that quality of 71% TW waters was not suitable for irrigation purpose due to higher concentration of soluble salts. The concentrations of chemical constituents in water from the LBDC aquifer system vary both depth and location wise. The application of TW irrigation having different salinities added substantial amount of soluble salts into soil that affected the soil quality. Resultantly, the yields of different crops reduced from 3 to 15%. Presently the farmers are using brackish TW water with CW but the continuous use of poor quality irrigation water would have serious consequences for sustainability of soil and crop productivity in the area.

Keywords: Tubewell water quality; soil quality; crop yield; EC; SAR; RSC.

1. INTRODUCTION

Water quality is an important factor when considering an irrigation programme. The common water quality parameters are electrical conductivity (EC), sodium adsorption ratio (SAR) and residual sodium carbonate (RSC) [1]. The canal water supply is not sufficient to meet the water requirement of the crops raised under intensive cropping system of Punjab, Pakistan. Hence, farmers are forced to meet this deficit through tube wells water which, over 70% is of poor quality [2,3].

Soluble salts in irrigation water, if present in sufficient quantity, affect soil quality and crops yields. Soil degradation has been defined as a reduction in soil quality in response to natural or anthropogenic causes, in a manner, that reduces current or potential productivity [4]. Soil degradation reduces the productivity of soil and water resources in many areas of the world, causing reductions in crop yields, higher production costs, and lower net income from agriculture. The economic impacts of sol degradation might be moderate when viewed from global perspective, but the impacts are severe in selected areas [5]. Policy reforms and public investments are needed in those areas to reduce soil degradation, improve rural income, and enhance food security [6]. The most severe aspect of soil degradation on Asian lands is soil salinity that has occurred through the accumulation of salts, mainly deposited from saline irrigation water or through mismanagement of available water resources [7]. The historical lands of Iran, Pakistan, Afghanistan, India and China are also subject to ancient and ongoing soil degradation processes which are subtle in some areas but evident and drastic in others.

The effect of different water qualities on soil health and crop yield is governed by many factors including water quality (amount and kind of salts), soil texture, crop species, climate (rainfall and temperature) and management practices. [8,9]. The results of a long term study of the effects of TW of EC 2.40 dSm^{-1} and SAR 9.20 (m mole $L^{-1})^{0.5}$ on soil properties showed that soil EC increased from 2.98 to 4.55 dSm^{-1} and SAR increased from 10.8 to 18.9 (m mole $L^{-1})^{0.5}$ after 7 years [9]. Similar results have been reported by other [10]. The negative effects of brackish water on the yields of wheat grain, paddy, berseem, maize fodder [9,11] and sunflower [12] have been reported. The wheat grain yield from field irrigated with TW was found to be more affected by the sodicity compared with salinity of water [13].

Little attention is paid by farming community to keep the land productive in Pakistan. The pre-requisite for the safe use of poor quality water is to know the amount and kind of salts in irrigation water. Limited data on the quality status of TW waters in Lahore [14], Kasur [15], Gujarat [16], Rawalpindi [17], Jhang [13], Sahiwal [3] and other districts of Punjab is available. But systematic and comprehensive information on

TW water quality and its implications on soil and crop productivity are not sufficient in the south Punjab of Pakistan. Therefore, a detailed survey of district Sahiwal was carried to collect TW water and soil samples along with yields data of crops grown in the area. The detailed information on ionic concentrations of water samples at village levels and remedial measures for the safe use of brackish water has been submitted elsewhere. In this report we will discuss (i) overall quality status of TW waters for irrigation and, (ii) quantification the effect of TW water irrigation on soil quality and some selected crops yields in the study area.

2. METHODOLOGY

2.1 Description of Study Area

Sahiwal district (30°39′52″N 73°6′30″E) occupies central part of Punjab Province, Pakistan, and situated in a semiarid region that is flood irrigated with canal and tubewell waters. The parent material is alluvium formed by the Ravi and Sukh Bias rivers. It is highly productive and texture varies from silt loam to clay loam and clay type. Saline-sodic soils also exist in the district. The major crops grown are cotton, rice, and maize, sugar cane in Kharif and wheat and potato in Rabi season with cropping intensity > 200%. The annual rainfall ranges from 150 to 200 mm. The average maximum temperature during summer usually remains 40-45ºC. The winter is cold and dry and the average minimum temperature is 4-5ºC during month of January.

2.2 Sampling

Out of 531 villages of Sahiwal district, 261 villages were randomly sampled for 529 TW in Canal Command Area (CCA) during 2012 and 2013 (Fig. 1). The CCA comprised of nine distributaries of Lower Bari Doab Canal (LBDC); four on right side (RD) namely, 4R, 5R, 6R and 7R; five on left side (LD) namely, 5L, 9L, 11L, 12L and 14L. Out of total 261, 105 villages were sampled from RD and 156 from LD. The samples were collected in plastic bottle after 30 minutes of TW operation. The depths of TW ranged from 61 to 152 m. Twenty composite soil samples, 10 from each Chichawatni and Sahiwal tehsils, were collected at 0 to 15 cm depth from the selected farmer fields irrigated with TW and CW to monitor the effect of poor quality water on soil health. The basis of soil and crop yield samplings was to cover representative area under three prevailing crop rotations namely; wheat-cotton-wheat, wheat- rice -wheat and maize- potato-maize. Total cultivated area of Sahiwal district under above mentioned crops was 766188 acres.

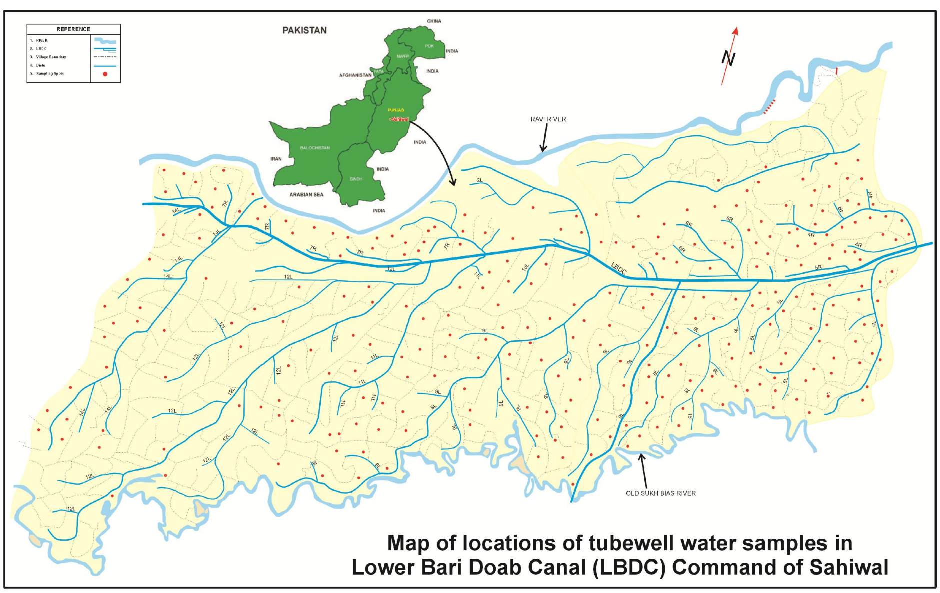

Fig. 1. Map showing locations of tubewell water samples in LBDC command of district Sahiwal, Punjab, Pakistan

2.3 Soil and Water Analyses

The analytical work was carried out at Soil and Water Testing Laboratory, Sahiwal. Soil samples were air-dried, ground and passed through 2 mm sieve and preserved in plastic bottles for analyses. Soils were analysed for pH_s, electrical conductivity of the saturated paste (ECe), and water samples were analysed for EC, cations (Ca^{2+} + Mg^{2+}, Na^+) and anions (CO^{2-} , HCO^-_3) by methods described by[18]. Total Dissolved Salts (TDS), Residual Sodium Carbonate (RSC), Sodium Adsorption Ratio (SAR) of water were computed [1] as given below and the criterion for the suitability of irrigation water is given in Table 1

TDS (mg L^{-1}) = EC (dSm^{-1}) × 640.

RSC (me L^{-1}) = (CO_3^{2-} + $HCO^-_{3)}$ - (Ca^{2+} + Mg^{2+}), where cations and anions in me L^{-1}

SAR (mmol $L^{-1})^{0.5}$ =Na^+/ [(Ca^{2+} + Mg^{2+})/2]$^{0.5}$, where cations and anions in me L^{-1}

Table 1. The criterion used for suitability of irrigation water [1]

Parameters	Fit	Marginally fit	Unfit
EC (dSm^{-1})	<1.0	1.0 – 1.25	> 1.25
RSC(me L^{-1})	<1.25	1.25 – 2.25	> 2.25
SAR(mmol $L^{-1})^{0.5}$	<6	6 – 10	>10

2.4 Estimation of Soluble Salts Addition to Soil with TW Water Irrigation

The quantities of soluble salts added into soil with the irrigation of TW of different qualities in the study area were estimated to assess their effects on soil quality. The basic equation [19] used to calculate the amount of salts addition with irrigation water is as under:

TDS (tons per acre ft) = TDS (mg L^{-1}) × 0.00136

TDS (tons per hectare) = TDS (tons per acre) × 2.471

In the sampling area the TDS of TW waters ranged from 218 to 3309 mg L^{-1} and this range was used to calculate that how much salts were added into soil with the application 0.30 m of water. Similarly, salts added to soil under different crops were calculated by considering consumptive use (CU) of wheat (425 mm), cotton (750 mm), rice (1500 mm), spring maize (1200 mm), autumn maize (750 mm) and potato (900 mm) [20] The highest level of water salinity (TDS 3309 mg L^{-1}) was used in these estimations. To make the understanding clear, the calculation for wheat is demonstrated.

CU of wheat=425 mm=1.4167 ft.

TDS of TW water used= 3309 mg L^{-1}.

Putting values in the above equation we get

TDS (tons per acre ft of water) = 3309 × 0.00136= 4.50

As the CU of wheat is 1.4167 feet, So TDS will be 4.50 × 1.4167=6.375 tons per acre=6.375×2.471=15.753 tons per hectare.

2.5 Crop Yield Data and Statistical Analysis

The yield data of wheat, cotton, maize and potato crops were recorded, according to the standard procedures, from 10 farmer's fields from each tehsil irrigated with CW and TW to compare the effects of brackish water on the yields. Some information on inputs regarding source of irrigation and fertilizers type (organic and inorganic), and rate of fertilizers application were also collected. The scarcity of CW forced the farmers to use poor quality TW water and they mix CW and TW waters to raise the crops. It was noted that >90% farmers used Diammonium phosphate (DAP) as source of phosphorus in comparison of Single supper phosphate (SSP). The sources of nitrogen were urea, Calcium ammonium nitrate (CAN). Now Ammonium sulphate (AS) is available in the market to replace urea and farmers are fully convinced as this fertilizer is acidic in reaction due to pH 4. The sources of potassium were potassium sulphate (SOP) and muriate of potash (MOP) and its use was limited to maize and potato crops. The maize and potato growers generally used 1.5 times nitrogen against the departmental recommendations. The range, mean and standard deviation of different soil, water and crop parameters were calculated [21].

3. RESULTS AND DISCUSSION

3.1 Quality Status of Tubewell Waters of District Sahiwal

Data (Fig. 2) on characterization of TW water samples based on EC, RSC and SAR showed that 71% TW were saline and >20% samples were sodic in nature [13-15]. The quality of TW water in RD was comparatively better than in LD due to its location between LBDC and Ravi River. The TW situated along LBDC had sweet water due to the seepage of CW. The more TW water samples on LD were brackish than RD and about 6% of the total TW samples had extreme values of EC, RSC and SAR. The use of such waters caused soil salinity and affected crops yields. The yields reductions were not to that extent because of sandy aquifer without any marked clay layers [22], use of flood irrigation of TW with dilution of CW and sowing of semi tolerant crop like wheat. Based on soil and water analyses, the farmers were advised proper management strategies for sustainable crop production. It was realized that those farmers who followed the departmental recommendations had harvested 3.30 t ha^{-1} wheat in Chichawatni and 4.13 t ha^{-1} in Sahiwal where most of times brackish TW was used to irrigate the fields.

The concentrations of chemical constituents in water from the LBDC aquifer system vary both depth and location wise. The deep groundwater quality investigations carried out by [23] showed that the distribution of saline and fresh groundwater zones in Bari Doab is a result of past and present hydrologic, climatic, and topographic factors. Among these, the present and former positions of stream channels, representing sources of recharge, the high bluffs of the bar uplands in the upper part of the Bari Doab, and differences in the permeability within the alluvial aquifer are the most important.

3.2 Impact of Tubewell Waters Irrigation on Soil Quality

The farmers of district Sahiwal used poor quality TW waters having EC 0.34 - 5.17 dSm^{-1} with SD 0.88 (TDS ranged from 218 to 3309 mg L^{-1}) for crop production due to the scarcity of CW. The use of these water qualities contributed to the soil salinity [24] leading to soil degradation. It was estimated that a huge amount of salts were added into soil with the application of 0.30 m irrigation water of different qualities (Fig. 3). Similarly, it was calculated that 55.599 t ha^{-1} soluble salts were deposited in soil under rice crop with the application of TW having TDS 3309 mg L^{-1} (Table 2).

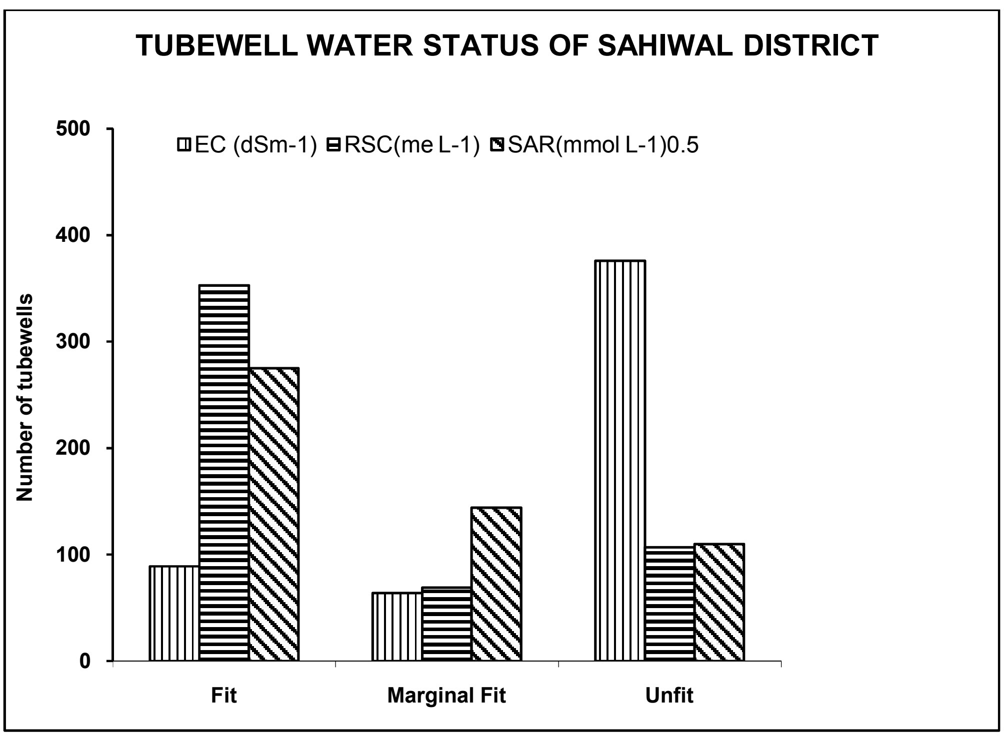

Fig. 2. Characterization of tube well waters (n=529) on the basis of EC, RSC and SAR of district Sahiwal

The effects of brackish irrigation water on soil salinity due to continuous use of poor quality TW was evaluated at farmer's field in two tehsils of district Sahiwal during 2012 and 2013 (Table 3). The EC of TW used for irrigation ranged from 1.00 to 3.62 dSm^{-1}. It was observed that soil EC increased from 2.06 to 3.62 dSm^{-1} in Chichawatni and 2.40 to 3.97 dSm^{-1} in Sahiwal tehsil with continuous use of TW. This data supported that substantial amounts of soluble salts were added to soils with the application poor quality TW irrigation as given in Fig. 3 and Table 2. However, the increase in soil salinity was not to that extent as it was expected. This was due to leaching of salts with the application of heavy flood irrigations by the farmers, light to medium textured soils and rainfall (457 mm) during the rainy season [3]. It means the significance of rainfall and leaching fraction in maintaining the soil health while using brackish water should be duly accounted for [8]. Similarly, the results of a long term study conducted on the effects of brackish TW on soil quality showed that after growing 12 crops following berseem-rice-wheat- maize fodder-berseem crop rotation, the non-saline and non-sodic soil was converted to sodic soil (SAR 18.9) by the use of TW [9]. Similar results were also reported by others [10,24].

Table 2. Quantity of soluble salts added to soil with tubewll water irrigation having 3309 mg L^{-1} TDS under different crops grown in district Sahiwal, Punjab, Pakistan

Crop	Consumptive use (mm)	Quantity of salts added (t ha^{-1})
Wheat	425	15.753
Cotton	750	27.801
Rice	1500	55.599
Potato	900	33.361
Spring maize	1200	44.480
Autumn maize	750	27.801

3.3 Impact of Tubewell Water Irrigation on Crop Yield

The effect of water quality on the yields of wheat, cotton, maize and potato crops was evaluated at farmer's fields of Chichawatni (Fig. 4) and Sahiwal tehsils of the district (Fig. 5). The yields of crops reduced from 3 to 15% in the fields where usually TW was used compared to CW irrigated plots. The yields of crops were not severely affected by TW water having EC up to 5.17 dS m^{-1} in LD because the lithologic logs of bore holes have shown sandy aquifer without any marked clay layers [22] and also due to the management practices adopted by the farmers [25]. The yield decrease is very limited because the farmers did not use TW water alone. They occasionally mixed a limited quantity of available CW with TW water. Secondly, the soil texture of the study area is loam to loamy sand. Thirdly, the progressive growers of maize and potato used heavy inputs in terms of FYM, DAP, SSP, AS, urea, gypsum and sulphur to harvest 16 to 17 t ha^{-1} potato and 8 to 10 t ha^{-1} spring maize. It was noted during survey that the farmers harvested optimum yields of crops with brackish TW following viable management practices. For example, the addition of farm manures, use of balanced fertilizer, proper type of fertilizers (use of SSP on sodic soils) and light irrigation of poor quality water proved better. Furthermore, the response of crops to different water qualities differed greatly due to different salt tolerance limits of salts by crops [26]. The use of brackish TW water (EC 2.40 dSm^{-1}; SAR 9.20 (mmol $L^{-1})0^{0.5}$; RSC 5.70 me L^{-1}) on crops grown under berseem-rice-wheat-maize fodder-berseem rotation on permanent layout during 1987-88 to 1993-94 reduced crops yields from 3 to 36% over CW [9]. Similar results were also reported by others [10,25]. The soluble salts exerted both general and specific effects on plants which reduced crops yields.

Table 3. Range, mean and standard deviation of ECe at farmer's fields irrigated with canal and tubewell water in two tehsils of Sahiwal district during 2012-13

Location	Source of irrigation	*Range	Mean	Standard deviation
Chichawatni Tehsil	Canal water	1.75-2.41	2.06	0.24
	[a]Tubewell water	2.99-4.01	3.62	0.41
Shiwal Tehsil	Canal water	1.95-2.80	2.40	0.36
	[b]Tubewell water	3.65-4.36	3.97	0.27

**Mean value of 10 farmer's fields in each tehsil; [a]EC ranged from 1.00 to 2.82 with mean 1.9±0.79; [b]EC ranged from 1.12 to 3.62 with mean 2.14±0.0.99*

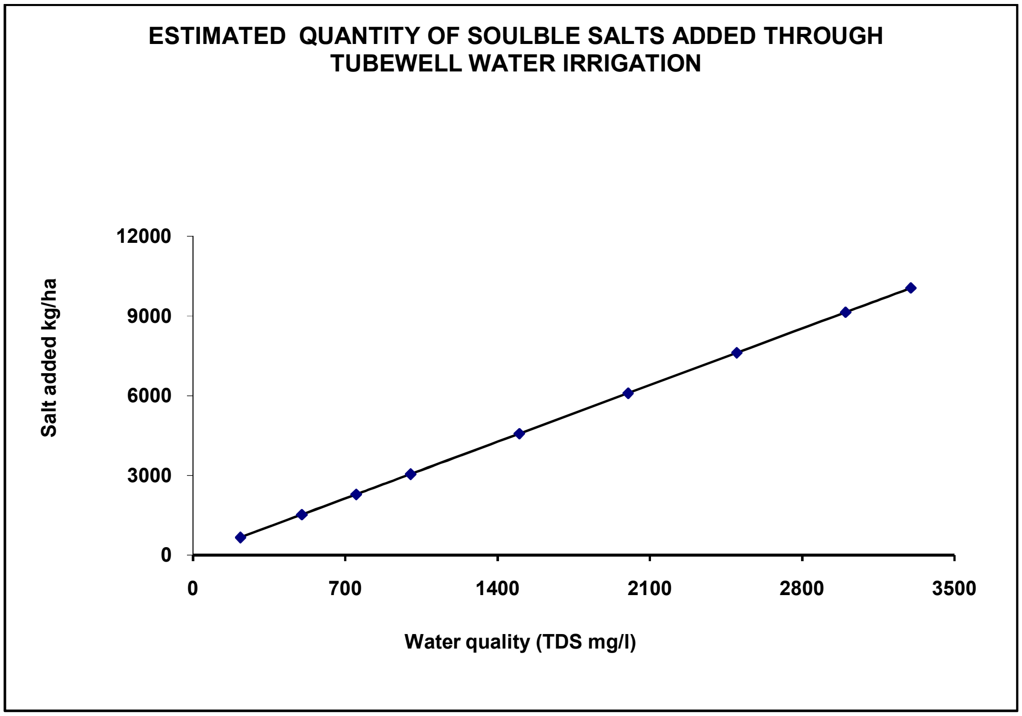

Fig. 3. Quantity of soluble salts added to soil with tubewell waters irrigation of 0.30 m depth of TDS 218 to 3309 mg L^{-1}

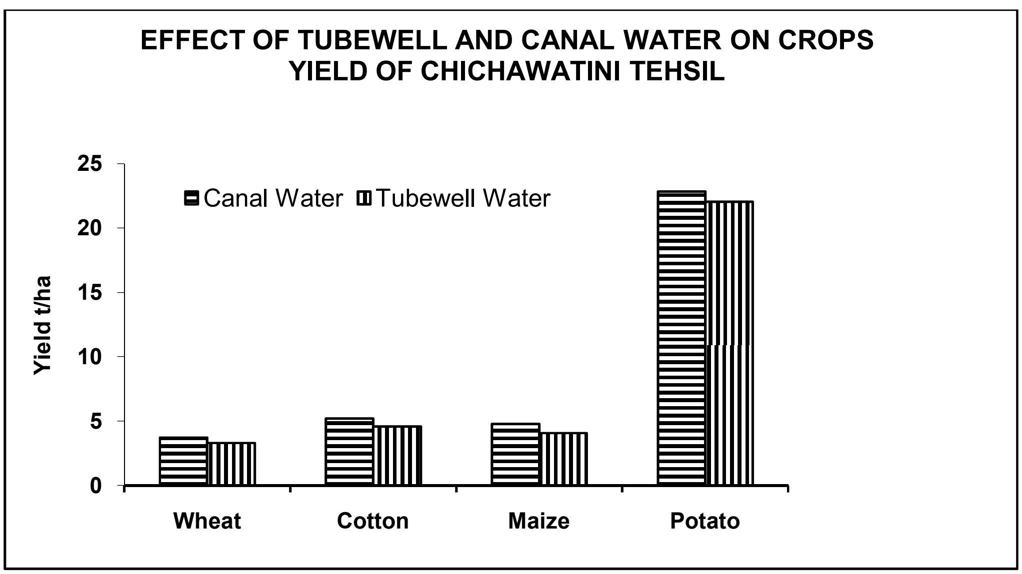

Fig. 4. Effect of water quality on the yields of crops at farmer's fields in Chichawatni tehsil of District Sahiwal

EC of TW waters ranged from 1.00 to 2.82 dS m^{-1} ; SD were ±0.61, ±0.77, ±0.19 ±1.85 for wheat, cotton, maize and potato yields in canal irrigated fields, whereas, SD were ±0.57, ±0.72, ±0.13, ±1.20 in tubewell irrigated fields, respectively

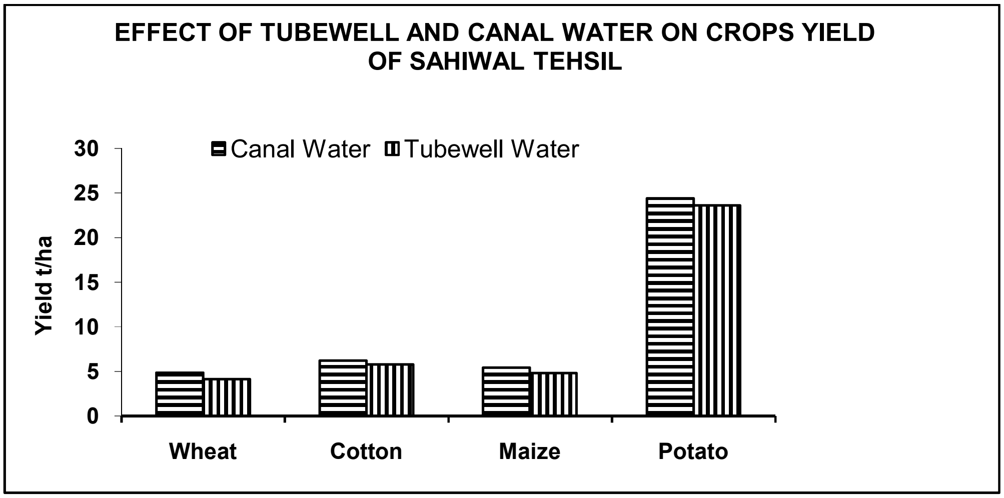

Fig. 5. Effect of water quality on the yields of crops farmer's fields in Sahiwal tehsil of district Sahiwal

EC of TW waters ranged from 1.12 to 3.62 dS m^{-1} ; SD were ±0.91, ±0.73, ±0.65,±1.80 for wheat, cotton, maize and potato yields in canal irrigated fields, whereas, SD were ±0.80, ±0.63, ±0.12, ±1.79 in tubewell irrigated fields, respectively

4. CONCLUSION

Data on quality status showed that more than 71% TW were saline and >20% were saline or sodic in nature. The concentrations of chemical constituents in water from the LBDC aquifer system vary both depth and location wise. It was estimated that application of TW irrigation having different salinities added substantial amount of soluble salts into soil that affected the soil quality. Resultantly, the yields of different crops reduced from 3 to 15% with the use of poor quality irrigation water. Presently the farmers are using brackish TW water with CW but the continuous use of poor quality irrigation water would have serious consequences for sustainability of soil and crop productivity in the area.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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