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***Corresponding Author**
Abid Niaz
E-mail
draniazch@gmail.com

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Boron Concentration in Irrigation Water Used for Wheat-Cotton Cropping System in Alkaline Calcareous Soils of Southern Punjab

Abid Niaz[1]*, Sadia Sultana[1], Abdul Majeed[1], Ana Aslam[1], Abdul Wakeel[1], Ehsan-ul-Haq[1], Muhammad Aftab[1], Farah Rasheed[1], Atif Muhmood[1], Asifa Naz[1], Amina Kalsoom[1], Atta Muhammad Ranjha[2], Rahmat Ullah[2], Nazir Ahmed[2]

[1] Institute of Soil Chemistry and Environmental Sciences, Ayub Agricultural Research Institute, Faisalabad, Pakistan
[2] Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad, Pakistan.

Abstract

Boron (B) is an essential plant nutrient, but in Pakistan, farmers don't have awareness about this important microelement. Global research showed that B exists in substantial amounts in irrigation water (both surface and groundwater). This study was planned to assess the boron content in canals and tube well irrigation water directly used for wheat and cotton crops in southern areas of Punjab, Pakistan. Total 109 surface water samples were collected from different canals and their distributaries during winter (December-January) and summer (July-August) months and were analyzed for pH, electrical conductivity (EC), and B concentration. The results indicated that B concentration ranged from traces to 0.42 mg L^{-1} with a mean value of 0.11 mg L^{-1} during winter season while pH and EC varied from 6.89 to 8.10 and 0.10 to 1.87 dS m^{-1}, respectively. However, higher B concentration was noted in canal water samples collected during monsoon season and it ranged from 0.01 to 0.63 mg L^{-1} with an average value of 0.17 mg B L^{-1}. The B content in 112 tube well water samples ranged from traces to 1.29 mg L^{-1} and the average EC, pH and B of tube well water samples were 2.45 dS m^{-1}, 7.62 and 0.26 mg B L^{-1}, respectively. These results revealed that tube well water samples had obviously more B concentration then canal water samples. This study concluded that both canal and tube well water irrigation sources used for wheat-cotton production under alkaline calcareous soils of southern Punjab contained substantial amounts of B and these irrigation waters fulfill the B requirements of both crops.

Introduction

Boron (B) is widely distributed in surface and ground-waters as the majority of well-waters had considerable amounts of B, whereas the surface water or canal water has concentrations in the range of 0.10 to 0.30 mg L^{-1} [1-3]. Global studies showed that B concentrations in surface waters had ranged from 0.001 mg L^{-1} to as much high as 360 mg L^{-1} with average B concentration up to 0.60 mg L^{-1} [4-6]. It has also been well established that there is a very narrow window between B adequacy and toxicity and occasionally B may possibly be toxic at even very low concentration. At times, B concentration <1.0 mg L^{-1} in irrigation water has been turned critical for plant development, but sometimes high B levels can cause problems, especially in sensitive or non-tolerant species. The main source of anthropogenic B comes from domestic/urban effluents (~1 mg L^{-1}) owing to the usage of bleaching agent like per-borates [7]. The broad-spectrum concept about the amount of water for irrigation purposes is well understood by everyone yet the quality of it is least understood. While considering crop inputs, there is no other input that is practiced at the rates that water (~102786 L ha^{-1}) and its contents are added, and thus far the majority of farmers give no cautiousness about the irrigation water. In nature, B is never found in the free or elemental state, but occurs in the form of boric acid or more commonly as borates, especially in regions that are or have been volcanic. It may also present in boro-silicate clay minerals [8].

In Pakistan, there is a severe shortage of good quality canal water; consequently, farmers use groundwater for irrigating the crops. The national reports showed that 957916 tube wells are working in Pakistan [9]. About 19.12 M ha lands of Pakistan are irrigated by different sources in which 7.06 million hectares are categorized as canal irrigated, 7.78 M ha canal + tube wells, 3.58 M ha tube wells, 0.28 M ha wells, 0.20 M ha canal + wells and 0.22 M ha are irrigated using other sources. The irrigation water (either surface or canal) contained many mineral nutrients including boron. Worldwide studies showed that average surface water B concentration in the USA is about 0.10 mg L^{-1}. The reported data on 1577 samples illustrated that B was detected in 98% samples and B concentration was ranged from 0.001 to 5 mg L^{-1} [10]. The concentration of B in seawater is relatively more than fresh waters and sometimes it reached up to 4.5 mg L^{-1} [11]. An average concentration of 1 mg B L^{-1} was reported in sewage effluents in California [12, 13]. In the UK, Waggott [14] reported that B concentration in municipal sewage in a treatment plant ranged from 2.5 to 6.5 mg L^{-1}, releasing between 130 and 240 kg B per day. Scientists also reported the reuse of this municipally treated water for citrus orchards [15, 16]. Conversely, the findings of Jain and Saxena [17] concluded that the distribution of soluble ions including B in soil varied in relation to irrigation waters. Moreover, the river waters had the greatest B content at dissimilar time-periods of the year owing to the contribution of spring drainage areas high in B [18, 14]. Pakistan has about 80 M ha total area out of which only 22 M ha is the total cultivated area. In Pakistan, more or less 19.12 M ha lands are irrigated by the canal, wells, tube wells and other sources alone or in combinations [9]. The climate is arid to semi-arid and average annual rainfall is very low. There are two main seasons: Rabi (September–March) and Kharif (April – September). The magnitude and genus of minerals varied spatially or with times depending upon the rainfall patterns. Quantities of minerals are exceptionally supportive simply when they are in low concentrations, but if higher concentrations are present in water, then they may be toxic to both flora and fauna [5, 19].

Data from ground-water and surface water indicated that B occurred in 20% of the sites at a geometric mean concentration of 156 ppb (0.156 mg B L^{-1}) in groundwater samples and at 5% of the sites at a geometric mean of 1177 ppb (1.18 mg B L^{-1}) in surface water [20]. When irrigation water is applied, the mineral salts are left in the soil after the crop has used the water [21, 22]. Most of these mineral salts are beneficial to crop growth and soil condition, but in some circumstances (the excess B) may be harmful to plants [23, 24]. Wheat-cotton crop rotation is one of the main cropping systems in Pakistan, especially in Southern regions/districts of Punjab. Generally, farmers of these areas applied fertilizer NPK only to both wheat and cotton crops and don't apply any micronutrient except few progressive farmers. The information regarding micronutrient application and response is available in Pakistan, but there are no data about the addition of boron in soils through irrigation water in Southern Punjab, especially under the wheat-cotton cropping system. So keeping in view the importance of B, this study was initiated to assess the boron content in irrigation water either canal or tube well, directly used for wheat and cotton in wheat-cotton cropping scheme areas of southern Punjab, Pakistan.

Materials and Methods

Collection of water samples and analysis

Water samples were collected from different canals, main distributaries and water channels during the winter and summer months from Jhang, Toba-Tek-Singh, Multan, Vehari and Faisalabad districts and the groundwater samples were also collected from tube wells installed at farmer's field from the same sites (Fig. 1). These samples were analyzed for pH, electrical conductivity (EC) and boron concentration by following the established methods [25, 26].

The method used for the determination of B concentration in the canal and well waters was spectrophotometric based on colorimetric reactions of B with azomethine-H [27]. The optical density of the analyzed solution is usually proportional to the boron concentration in water. The color was developed by using 2 ml filtrate and then 2 ml buffer-masking reagent was added along with 2 ml azomethine-H is coloring reagent in polypropylene flasks. All the material was thoroughly mixed by shaking and then kept for 25 to 30 minutes for color development. After that, absorbance was measured at 420 nm on UV 2020 Spectrophotometer [28]. The standard curve constructed by plotting absorbance versus concentration of standards in µg B ml^{-1} was determined and B concentration was determined using the following formula:

B (µg B ml^{-1}) in sample = µg B ml^{-1} × 10 ml final volume / sample volume (ml)

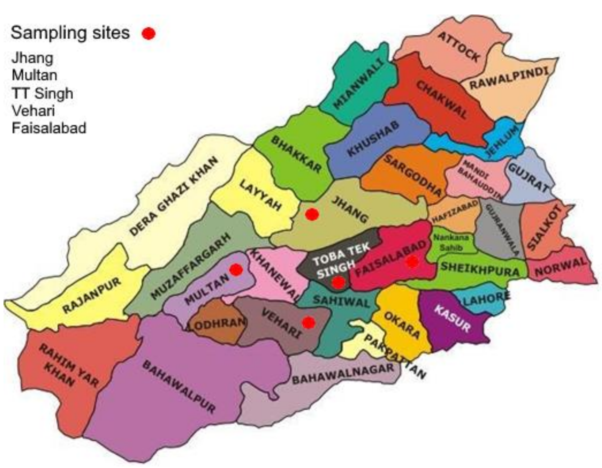

Fig. 1 Map of the sampling sites of wheat-cotton cropping system in southern Punjab, Pakistan.

Statistical analysis

All the data regarding water characteristics (pH, EC and B concentration) were subjected to statistical analysis (including average, standard deviation (SD) and range). The simple correlation was also done to estimate correlation coefficients between different soil properties and B concentration in soil. In addition, the regression analysis (regression equations and R^2 values) was also performed [29, 30].

Results and Discussion

Seasonal variation in chemical characteristics (B, EC and pH) of canal water samples

The cotton and wheat growing areas of Southern Punjab are generally irrigated with canal and tube well waters and the ratio varied depending upon the supply of canal irrigation water. So water samples were collected in both summer and winter seasons from the canals. Initially, total 122 surface water samples were collected directly from rivers, major canals, distributaries and water channels during the winter and summer months. All the samples were analyzed for pH, electrical conductivity (EC) and B content. The results exhibited that B was found in all the surface water samples, but it varied in both seasons. During winter months (December–January), the B concentration ranged from traces to 0.42 mg L^{-1} with a mean value of 0.11 mg L^{-1}. The pH of canal water samples was marginally higher (pH ≥ 7.00) and it ranged from 6.89 to 8.10 with a mean value of 7.24. The EC of water samples varied from 0.10 to 1.87 dS m^{-1} with an average value of 0.51 dS m^{-1} (Table 1).

The results depicted in Table 1, showed that B concentration in water samples during summer months (July-Aug) ranged from 0.01 to 0.63 mg L^{-1} with mean values of 0.17 mg B L^{-1}. Unlike winter season samples, the highest B concentration was increased up to 0.63 mg L^{-1}. The pH and EC varied from 6.69 to 8.00 and 0.28 to 1.65 dS m^{-1}, respectively, with the relevant mean values of 7.42 and 0.43 dS m^{-1}. These low EC values of canal water samples demonstrated that the majority of canal water samples had insignificant salt concentration; therefore this low EC water was quite fit for irrigation purposes. Simple correlation analysis (Table 2) clearly showed that EC of water (R^2=0.76 and R^2=0.77 at P<0.05) had a significant positive correlation with B concentration in both

Table 1 Analysis of canal water samples collected from different locations in Southern Punjab during winter and summer months.

Statistical parameters	Winter season			Summer season		
	B (mg L^{-1})	pH	EC (dS m^{-1})	B (mg L^{-1})	pH	EC (dS m^{-1})
Mean	0.11	7.24	0.51	0.17	7.42	0.43
Standard deviation	0.08	0.31	0.23	0.10	0.54	0.27
Range	Traces-0.42	6.89-8.10	0.10-1.87	0.01-0.63	6.69-8.00	0.28-1.65

seasons, whereas pH of water samples was not significantly correlated with B concentration (R^2=0.07 and R^2=0.12 at P<0.05).

Similarly, the regression analysis showed (Fig. 2) that the increased EC (R^2=0.55 at P<0.05) resulted in amplified B concentration of water and this increase was statistically significant, while pH of water (R^2=0.009) had no significant effect on B concentration (Fig. 3). These results are in accordance with the findings of many researchers [2, 17, 31, 32]. Similarly, some studies revealed that B had a significant relationship with other solutes in the irrigation water [33, 34]. The lowest concentration in canal irrigation water samples of the present study was not in the ranges of toxicity, and these are also supported by the findings of other scientists in which they revealed that only very little irrigation waters had toxic B concentrations which injured and or damaged plant roots or shoots directly [19]. As it is well established that B exists frequently as un-dissociated H_3BO_3 (boric acid) with some per-borate ions in irrigation water, therefore, B–O_2 compounds are sufficiently soluble in water to attain the levels that have been perceived [35]. Many soils and sediment residues adsorb merely water-soluble B, thus the ultimate fate of boron in that water is adsorption-desorption reactions [36]. These results obviously demonstrated that B concentration in canal water samples during the rainy season was comparatively higher than winter season samples. This enhanced B concentration in canal water samples during monsoon rainfalls might be due to higher silt and clay transportation from the hilly areas of Pakistan because, during monsoon rains (July – August), Pakistani rivers (*Indus*, *Jehlum and Chenab*) loaded and carried more silt and clay

Table 2 Correlation analysis of electrical conductivity (EC), boron (B) and pH of canal water samples.

Characteristics	EC in winter	EC in summer
EC	1.00	1.00
B	0.76**	0.77**
pH	0.07	0.12

particles along with nutrients (like K, Ca, S and B) than in winter season (January–February). Ultimately, with these particles B also moved with water from different minerals to canals and finally shifted to the fields through water [37]. Many researchers also supported these results and they revealed that the majority of the underground waters had assorted B concentrations and often had excessive B amounts whilst the surface waters or canal waters have B concentration of 0.10 to 0.30 mg L^{-1} [2, 21, 38, 39]. On the contrary, few scientists conducted experiments on the distribution of soluble ions comprising B in the soil in relation to irrigation waters and they concluded that river waters had high B levels at different times of the year due to the contribution of spring drainage areas high in B [17, 15]. Monthly average B values in the Ruhr River (Germany), varied from 0.31 to 0.37 mg L^{-1} during 1992–1995 [40]. However, boron concentrations in fresh surface water varied from <0.001 to 2 and 0.01 to 7 mg L^{-1} in Europe and Russia, Pakistan and Turkey, respectively; whereas the boron concentration of Japanese and South-African water was ranged 0.01-0.30 mg L^{-1} [41, 37, 43].

Chemical characteristics (B, EC and pH) of groundwater (tube well) samples

Total 90 tube well water samples (20 from each district) were collected from farmer's fields situated in different villages of districts of Jhang, Toba-tek Singh, Faisalabad, Multan and Vehari. The results revealed that B concentration in groundwater samples was more than canal water samples from the same sites. The concentration of B in tube well water samples varied from traces to 1.36 with a mean value of 0.26 mg B L^{-1} (Table 3). In this case, the higher SD value (0.14) indicated diverse variation in concentration of B of different tube well water samples. The maximum B concentration found in underground water samples was 1.36 mg B L^{1}. This high B concentration in some tube well waters samples clearly indicated that high B may cause some toxicity in B sensitive crops. The data also depicted that the average EC and pH values

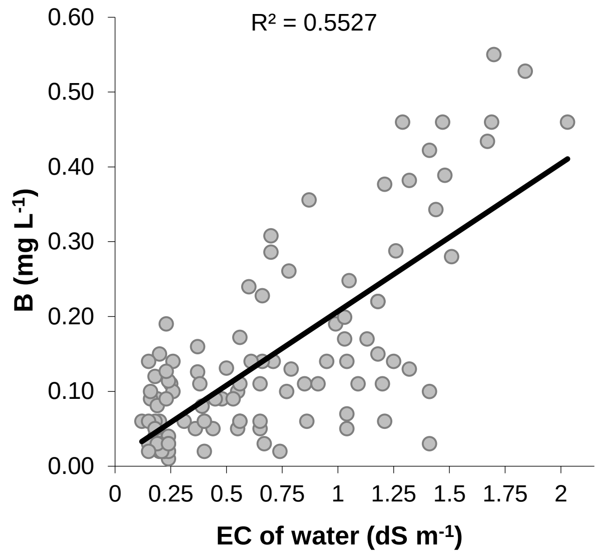

Fig. 2 Relationship of electrical conductivity (EC) and boron (B) concentration of canal water samples collected from different locations in Southern Punjab during winter and summer months.

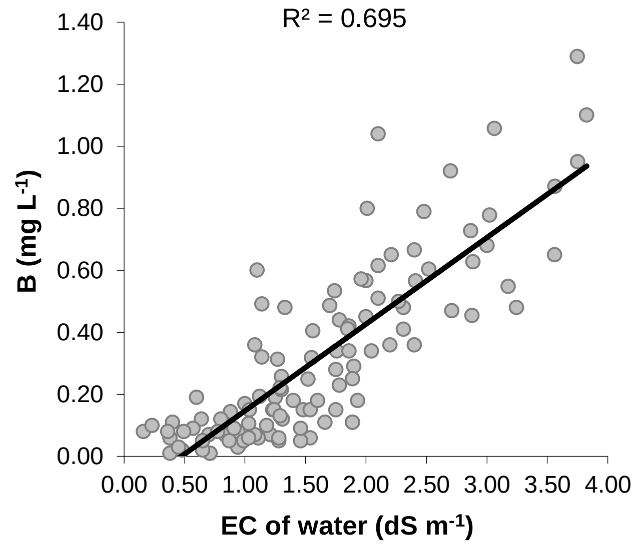

Fig. 4 Relationship of electrical conductivity (EC) and boron (B) concentration of tube well water samples collected from different locations in Southern Punjab.

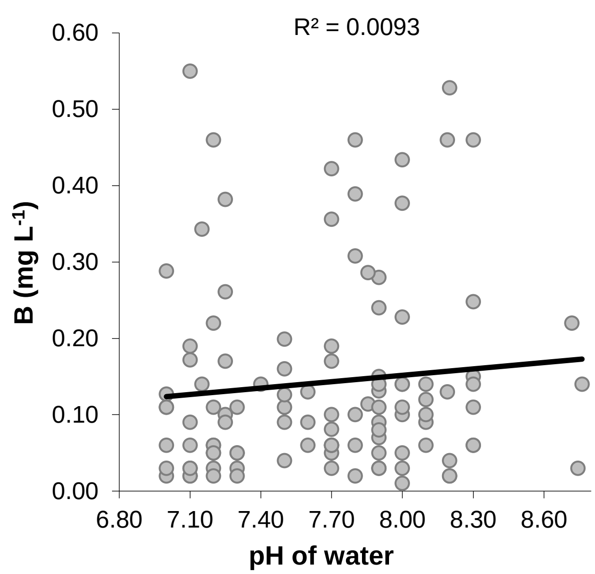

Fig. 3 Relationship of pH and boron (B) concentration of canal water samples collected from different locations in Southern Punjab during winter and summer months.

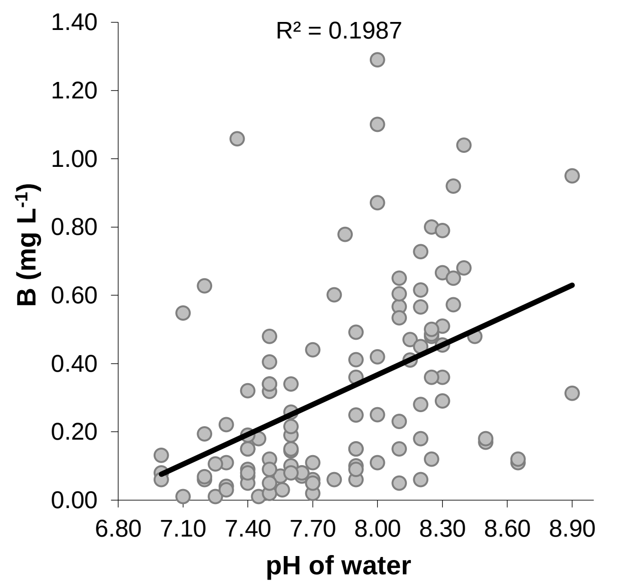

Fig. 5 Relationship of pH and boron (B) concentration of tube well water samples collected from different locations in Southern Punjab.

were 2.45 and 7.62, respectively, while it varied from 0.55 to 4.12 dS m^{-1} and 6.90 to 8.40, respectively (Table 3). The simple correlation analysis was also performed and it showed that EC (R^2=0.79 at P<0.05; n=90) and pH (R^2=0.61 at P<0.05) of water had a significant positive correlation with B concentration (Table 4). The regression equation and linear relationship (R^2=0.70) indicated that enhanced EC values substantially increased the B concentration in water (Fig. 4 and Fig. 5). These results are absolutely in conformity with the findings of other researchers [33].

The B concentration reported in the present

Table 3 Analysis of tube well water samples collected from different locations in Southern Punjab.

Statistical parameters	B (mg L^{-1})	EC (dS m^{-1})	pH
Mean	0.26	2.45	7.62
Standard deviation	0.14	0.71	0.29
Range	Traces-1.36	0.55-4.12	6.90-8.40

study was also supported by many other studies in which, they reported 0.60 mg L^{-1} B concentrations in underground water samples from the Netherlands and UK [42]; in Spain and Italy it ranged from 0.50 to 1.50 mg L^{-1} [42], whereas in France, Turkey, Germany and Denmark it was 0.30, 0.10 and 0.30 mg B L^{-1}, respectively [41, 43-45]. The relationship (R^2=0.20) of water pH and water B concentration showed that B concentration in water samples was non-significantly affected by pH of water (Fig. 5).

Table 4 Correlation analysis of electrical conductivity (EC), boron (B) and pH of tube well water samples.

Characteristics	B
B	1.00
EC	0.79^{**}
pH	0.61^{**}

Conclusions

It is obvious from the present study that both (canal and tube well) irrigation sources significantly added good amounts of B in alkaline calcareous soils of wheat-cotton growing areas of southern Punjab. The boron concentration in groundwater samples was substantially higher than canal water samples when compared to both sources of irrigation water. There was a considerable temporal variation in B concentration of canal water samples and more B was found in monsoon (summer) then winter season. Correlation analysis clearly showed that EC of the water had a significant positive correlation with B concentration, whereas pH of water samples was non-significantly correlated with B concentration.

Conflict of interest

The authors declare that they have no conflict of interest.

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