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Assesment of Boron in Soil, Plant and Irrigation Water under Cotton-wheat Cropping System of Northern India

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ABSTRACT

Background: The use of high yielding varieties, high analysis fertilizers and intensive cultivation has depleted the fertility of soils particularly with respect to micronutrients. The deficiency of B is expected to be high in coarse-textured soils having low organic matter, high $CaCO_3$ and high pH.

Methods: Geo-referenced surface (0-15 cm, n=155) soil samples, cotton leaves at pre flowering stage (n=75), wheat flag leaves (n=80) and tube well water (n=75) samples were collected from Bathinda, Mansa and Muktsar districts of Punjab.

Result: About 5, 18 and 20 per cent of soil, cotton and wheat samples were deficient in B, respectively. Hot water soluble B in soil was significantly positively correlated with pH (r= 0.230*), ESP (0.680**), B concentration in leaves of cotton (r=0.259*) and wheat (r=0.531**) but negatively with $CaCO_3$ in soil (r= -0.210*). About 40 per cent of tubewell waters had >2.0 mg B l^{-1}. On an average, one cm ha of tube well water may add up to 93 g B ha^{-1} to soil.

Key words: Boron, Cotton, Irrigation, Wheat.

INTRODUCTION

Boron (B) is a unique non-metal micronutrient required for normal growth and development of plants. The use of high yielding varieties, high analysis fertilizers and intensive cultivation has depleted the fertility of soils particularly with respect to micronutrients (Niaz *et al.,* 2007; Rashid, 2005). Calcareous and coarse textured soils which are highly leached exhibited boron deficiency to a greater extent as compared to other soils (Borkakati and Takkar, 2000).

In the Punjab state of northern India, available B in soils has been reported to be 0.40 to 7.49 mg kg^{-1} soil (Katyal and Agarwala, 1982). Singh and Nayyar (1999) have reported B deficiency in alluvial soils of arid and semi-arid regions of Punjab. However, B toxicity in saline soils of Punjab has also been reported (Arora and Chahal, 2005) because the critical range between the deficiency and toxicity limit for B is very narrow as compared to other elements. Even during a single crop growth season, both deficiency and toxic conditions can appear on the same crop (Reisenauer *et al.,* 1973). As the soils of Punjab are coarse textured and low in organic matter and being extensively cultivated therefore the possibility of B to be leached down to the deeper layers beyond the root zone is more likely in these soils. Saline soils and saline well water are found to be associated with high concentrations of B (Dhankhar and Dahiya, 1980).

The soils of south-west Punjab are alkaline and calcareous. Moreover, the irrigation waters are also saline. Crop species have different capacities for their uptake of B when they are grown in same media. Interaction of B with other plant nutrients, either synergistic or antagonistic also affects the plant uptake of nutrients under both the deficient and toxic conditions. The differences observed in response to B application are generally due to the use of different media for growth, crop cultivar and environmental factors. Therefore, a complicated relationship can be expected between B and utilization of other plant nutrients. The information regarding the present status of boron in soils, plants and irrigation water in cotton-wheat belt of Punjab is scanty. Thus, the present investigation was planned with the objectives to assess the boron status of soils, plants and irrigation waters in cotton-wheat belt of Punjab.

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MATERIALS AND METHODS

This study was conducted in the south-western region of Indian Punjab. Seventy five geo-referenced surface (0-15 cm) soil samples along with tube well waters were collected from different sites representing diverse soil series *viz.* Ustic Torripsamments, Typic Ustochrepts, Typic Ustipsamments, Ustochreptic Camborthids and Typic Ustorthents. Cotton leaf samples (3^{rd} fully matured leaf from the apex) were also collected from the same sites. Similarly, eighty surface soil samples and flag leaves of wheat were collected from different sites.

Soil samples were collected, air-dried, ground in a wooden pestle and mortar and sieved through ~2 mm mesh size sieve. The B in soil was determined using hot water soluble method while in plants, it was determined through dry ashing. The concentration of boron in soil and plant extracts was estimated by developing colour with azomethine-H (Wolf 1974). Ten g soil was weighed in 250 ml conical flask (boron free) fitted with a cork and glass tube. Twenty ml distilled water was added and kept for few minutes. Flask was heated until first sign of boiling appeared and then refluxed the contents for exactly 5 minutes. The contents were allowed to cool at room temperature and filtered through Whatman No. 42 filter paper. For colour development, 1 ml of filtrate was taken in a 10 ml volumetric flask to which 2 ml of buffer and 2ml of azomethine-H reagent was added. The colour was allowed to develop for 1 hour. Intensity of the yellow colour was measured at 420 nm. Concentration of B was read against the reading from the standard curve.

Statistical analysis

The experimental data was analysed by using SPSS software (Steel and Torrie, 1980). The data was also subjected to linear correlations analysis to establish the relationship between soil and plant parameters. For this data for all the soil samples (n=155) collected after cotton and wheat crops were taken together.

RESULTS AND DISCUSSION

Relationship of hot water soluble boron (HWS-B) in soil with soil properties

The data on the selected physico-chemical properties of the soils collected from different sites under cotton and wheat are given in Table 1. On the basis of critical deficiency level of 0.5 mg HWS-B kg^{-1} soil, only 5% of the samples were found deficient in available B. The reason for the low deficiency may be attributed to the high organic matter content of the soils and addition of boron through irrigation water.

Soil pH

A significant positive correlation of HWS-B with soil pH was observed (r= 0.230*, Table 1). Linear regression (y=0.706×-3.492) analysis of HWS-B with soil pH also revealed a positive relationship between the two thereby indicating that as the soil pH increased, HWS-B in soil increased. These results are in conformity with those of the Niaz *et al.* (2007).

Soil organic carbon

Soil organic carbon produced a significant and positive correlation with HWS-B (r= 0.188*, Table 1). Linear regression analysis of organic carbon with HWS-B (y=-0.080×+1.832) showed a positive relation of boron with SOM. Other studies also showed a positive correlation between SOM and HWB-B (Niaz *et al.,* 2007; Shafiq *et al.,* 2008). It is due to the fact that organic matter provides positive sites for the adsorption of negatively charged borate ions, thus reducing its leaching losses from the surface of soil.

Calcium carbonate

A significant negative coefficient of correlation of HWS-Bwith $CaCO_3$was observed (r=-210*, Table 1). Linear regression (y=-0.160×+2.663) analysis of these two parameters indicated a negative relationship. Similar were the findings of Niaz*et al* (2013) and Padbhushan and Kumar (2015). It is due to the bonding of B with $CaCO_3$ which results into precipitation of Ca-borate or substitution of carbon by B in $CaCO_3$ or simple surface adsorption of B on $CaCO_3$ (Keren and Ben-Hur, 2003). The cotton growing areas of Punjab are mainly calcareous in nature and calcium carbonate is the major factor which affects the availability of boron in soils.

Exchangeable sodium percentage

Hot water soluble B produced a positive and highly significant correlation with exchangeable sodium percentage (r = 0.680**) (Table 1). This increase in the easily soluble B content of the soils as a result of the increase in the Na content of the soils can be explained with the formation of highly soluble sodium tetra borate. Colak *et al* (2013) also reported a significant correlation (r=0.547**) of ESP of the soils with HWS-B. Regression analysis (y=0.178×+1.484) of ESP and HWS-B also produced a linear relationship with an R^2 value of 0.462.

Available phosphorus and potassium

The results showed a positive and highly significant correlation between available P and HWS-B (r = 0.341**) (Table 1). Harada and Tamai (1968) also observed a positive relationship of available P with HWS-B. This is due to the fact that B is adsorbed on the same soil constituents to which P is adsorbed. Linear regression analysis established a highly positive relation between available P and HWS-B (y=2.319x+35.69). The results showed a positive and highly significant correlation between available K and HWS-B (r = 0.229**). Linear regression analysis established a highly positive relation between available P and HWS-B (y=24.16+191.2). Oskoie *et al* (2014) also reported positive and significant correlations between HWS-B and available P (r=0.174*) and available K (r=0.339*) in soils.

Soil texture

The soils were medium in texture from sandy loam to sandy clay loam. The HWS-B was negatively correlated with sand (r = -0.124) and positively with clay (r = 0.064), although correlation values were not significant. Linear regression analysis revealed a positive relation between clay content and HWS-B (y=-0.013×+3.204) while negative relation between sand and HWS-B (y=0.016× +1.982). The correlation between soluble boron and clay content was positive because it is common to find higher soluble boron contents in clayey soils than in sandy textured soils. Niaz *et al.* (2007) reported a poor correlation between extractable soil B and soil clay content (r = 0.10, not significant).

Table 1: Selected physical and chemical properties of surface soils collected from different sites under cotton and wheat crops.

Soil property	Cotton	Wheat
	Mean±SE	Mean±SE
pH (1:2)	8.64±0.03	8.06±0.03
EC (1:2) (dS m^{-1})	$0.40^{\pm0}.04$	0.62±0.03
SOC, $CaCO_3$ (%)	$0._{73}$±0.03, 1.74±0.23	0.74±0.03, 1.41±0.15
Available P and K (kg P ha^{-1})	$41.3^{\pm1}.91$, 308.8±12.2	56.8±2.67, 185.2±15.4
Ca+Mg (me $100g^{-1}$ soil)	$^{13}.64$±0.34	16.04±0.43
ESP (%)	4.77±0.63	5.65±0.49
CEC (cmol (p^+) kg^{-1} soil)	$^{7\cdot}32$±0.18	8.71±0.21
HWS-B (mg kg^{-1} soil)	$^{2}.31$±0.16	2.52±0.14
DTPA-Zn, Mn, Fe, Cu (mg kg^{-1} soil)	1.40±0.14, 3.93±0.13, 4.88±0.41, 0.57±0.04	1.70±0.20, 4.23±0.17, 15.47±1.94, 0.67±0.05
Sand, Silt and clay (%)	56.2±1.53, 18.1±1.42,25.7±0.65	65.8±0.99, 7.60±0.84,26.5±0.50
Textural class	Sandy loam to sandy clay loam	

Table 2: Multiple linear regression analysis of HWS-B with soil properties.

Regression equation	R^2
Y = -5.631 + 0.154 (ESP) + 0.015 (P) + 0.730 (pH) + 0.835 (SOC)-0.118 ($CaCO_3$)	0.602**
Y = -6.155 + 0.153 (ESP) + 0.017 (P) + 0.765 (pH) + 0.733 (SOC)	0.579**
Y = -5.331 + 0.152 (ESP) + 0.020 (P) + 0.718 (pH)	0.557**
Y = 0.867 + 0.168 (ESP) + 0.010 (P)	0.512**
Y = 1.483 + 0.179 (ESP)	0.463**

Y = HWS-B in soils (mg kg^{-1} soil).

Table 3: Principal component analysis of the statistically significant soil properties indicators.

Statistic	PC 1	PC 2	PC 3
Eigen value	2.014	1.287	1.128
% of variance	33.57	21.44	18.8
Cumulative %	33.57	55.01	73.8
Factor loading/Eigen vector variables			
Calcium carbonate	0.273	0.041	<u>-0.794</u>
Boron	0.333	0.155	<u>0.750</u>
Cation exchange capacity	-0.198	<u>0.893</u>	-0.050
Soil organic carbon	0.057	<u>0.808</u>	0.157
Sand	<u>-0.716</u>	-0.273	0.211
Potassium	<u>0.942</u>	-0.255	0.113

Underlined factor loadings are considered highly weighted.

Poor but positive linear coefficients of correlation of HWS-B with EC, CEC and DTPA-extractable Zn, Fe, Mn, Cu were observed (Table 1).

Multiple linear regression analysis

The data on multiple linear regression analysis of HWS-B in soil (Y) as a dependent variable with different soil properties is presented in Table 2. The soil properties like ESP, available P, Soil pH, soil organic carbon and calcium carbonate together explained about 60 per cent of variation in HWS-B in the soils, where ESP alone could explain about 46.3 per cent variation in HWS-B in soils. The ESP along with available P and soil pH explained about 55.7 per cent variation in the soils under study. The results of this study using multiple linear regression analysis as a tool indicated the importance of soil pH, ESP, $CaCO_3$, SOC and available P in controlling the availability of B in soils.

Principal component analysis

The minimum data set (MDS) was selected using the principal component analysis (PCA) to study the most important soil properties affecting the availability of HWS-B. The PCA of the six variables resulted in three principal components produced Eigen values >1 and accounted for 73.8 per cent of the variance in the data (Table 3). The three PC of the data in the present study was further subjected to varimax rotation which resulted in maximum relationship between interdependent variables by distributing the variance of each principle component. The PC 1 explained about 33.57 per cent of variance that included available K with positive factor loading (0.942) while sand gave a negative factor loading (-0.716). The PC 2 explained about 21.44 per cent variance which included soil organic carbon and CEC with positive factor loading of 0.808 and 0.893, respectively. Around 18.8 per cent variance was explained by PC 3 which included $CaCO_3$ and B with factor loading of -0.794 and 0.750, respectively. Thus, the final minimum data set comprised of $CaCO_3$, sand, SOC, CEC and available K. These soil properties have already been identified as factors which affect the availability of B in soils.

The soil properties selected through PCA were further put into a general ANOVA model using B as a dependent variable which is dependent on these soil properties to check the most highly weighted soil property which is affecting the

Table 4: Descriptive statistics of chemical properties of tube well water (n=75).

Statistical parameter	pH	EC (micro mhos cm^{-1})	Carbonate (me l^{-1})	Bicarbonate (me l^{-1})	Ca+Mg (me l^{-1})	Chloride (me l^{-1})	Boron (mg l^{-1})
Range	6.60-8.70	210-11900	ND-1.60	ND-30.60	1.50-37.0	1-59.20	ND-5.33
Mean±SE	7.83±0.85	3351±365	0.12±0.04	7.41±0.41	8.84±0.66	11.55±1.12	0.93±0.14

ND-Not detected.

Table 5: Linear coefficients of correlation of B concentration in irrigation water with soil, plant and water parameters (n=75).

	Characteristic	'r' value
Irrigation water	pH	0.246*
	EC	0.728**
	Carbonates	0.210
	Bicarbonates	0.174
	Ca+Mg	0.495**
	Chloride	0.591**
Soil	HWS-B	0.286**
Plant	Cotton leaf B	0.316**

**Significant at 1% level, *Significant at 5% level.

availability of B. The test revealed that the HWS-B was significantly influenced by the $CaCO_3$ content of the soils (R^2=0.377).

Boron concentration in cotton leaves, petioles and wheat leaves

The boron concentration in cotton leaves ranged from 33.7-100.7 mg kg^{-1}, petioles (25.2-90.1) and wheat leaves (1.94-77.3) in 75 samples. The concentration of B was higher in cotton leaves than the petioles. The critical deficient concentration of B in cotton leaves is reported to be about10 to 35 mg kg^{-1} (Cassman, 1993). On the basis of the critical deficient level of 35 mg B kg^{-1}, about 18 per cent of the cotton samples were deficient. A significant positive coefficient of correlation of HWS-B with B concentration in cotton leaves (r=0.259*) was observed. Boron concentration in cotton leaves and petioles was also significantly positively correlated with each other (r= 0.361**). On the basis of critical deficient level of 15 mg B kg^{-1} in wheat leaves (Marschner, 1995), about 20 per cent of the samples were B deficient. Many other workers have also reported B deficiency in cotton and wheat crops (Rashid *et al.,* 2005; Zia *et al.,* 2006). A significant positive coefficient of correlation of HWS-B with B concentration in wheat leaves (r=0.531**) was observed. The symptoms of B deficiency were not observed in these crops indicating that they might be suffering from hidden hunger of B. Gupta (1993) considered that wheat (*Triticum aestivum*) was B deficient when B tissue concentration was below 10-20 mg kg^{-1}. In general, dicots (cotton and leguminous plants) have 4-7 times higher B requirement (20-70 mg B kg^{-1}) than monocots (graminae family, 5-10 mg B kg^{-1} (Marschner, 1995).

Quality of irrigation water

Groundwater is also considered to be a potential source of B for crops. Descriptive statistics of groundwater analysis for pH, electrical conductivity, carbonates, bicarbonates, calcium + magnesium residual sodium carbonate, chlorides and B concentration is presented in Table 4. The ground water analysed in the present study was high in soluble salts. The boron concentration in tube well waters ranged from nil to as high as 5.33 mg B l^{-1} with a mean of 0.93±0.14 mg l^{-1} thereby indicating that on an average one cm ha water may add up to 93 g B ha^{-1}. So, B concentration in some of the tube well waters was invariably high.

The concentration of B in irrigation water was significantly positively correlated with pH, EC, carbonates, bicarbonates, Ca+Mg and chlorides concentration (Table 5). The linear regression analysis also revealed a significant positive relationship of B concentration in irrigation water with its pH, EC, Ca+Mg and chlorides concentration (Fig 1a,b,c,d). Niaz *et al.* (2007) also reported a significant linear relationship between EC and B concentration of water but a non-significant between pH and B concentration for ground water B in Pakistan. Boron has no measurable effect on the physical properties of soils but can be toxic to sensitive plants at quantities of greater than 2.0 ppm. Boron content in irrigation water is still not considered for characterization of irrigation water. Boron is not as readily removed from the soil as chloride or nitrate but most of it can be removed by successive leaching. A continuous use of irrigation water containing boron may cause accumulation in toxic amounts. Boron accumulation takes place at a faster rate as boron is difficult to leach down. Our results showed that the irrigation water contained invariably high B content but the toxicity of B in crops is seldom observed. This may be due to the fact that the soils of the south western districts of Punjab are high in calcium carbonate. As soil B was negatively correlated with the $CaCO_3$ in soils, the adsorption of B might have occurred on $CaCO_3$ which reduces the toxicity.

The linear regression analysis of B concentration in irrigation water using HWS-B in soil and B concentration in cotton leaves revealed a positive relationship (Fig 2 a, b). Boron concentration in irrigation water was significantly positively correlated with HWS-B in soil (r=0.286**) and also with B concentration in cotton leaves (r=0.316**), thereby indicating that in south western districts,under cotton-wheat belt of Punjab, irrigation water can serve as a potential source of B for crops. These results suggested that the ground water B exhibited a large effect on the B in soil and its concentration in plants.

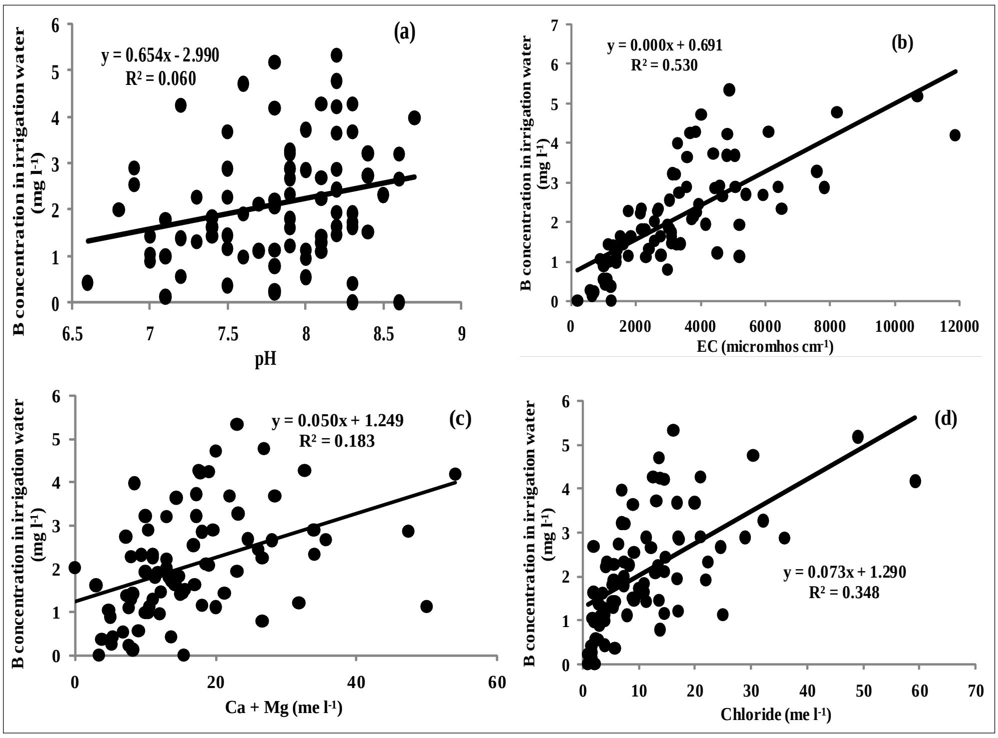

Fig 1: Relationship of B concentration in irrigation water with pH (a); Electrical conductivity, (b); Ca+Mg, (c) and chloride, (d); Concentration in irrigation water.

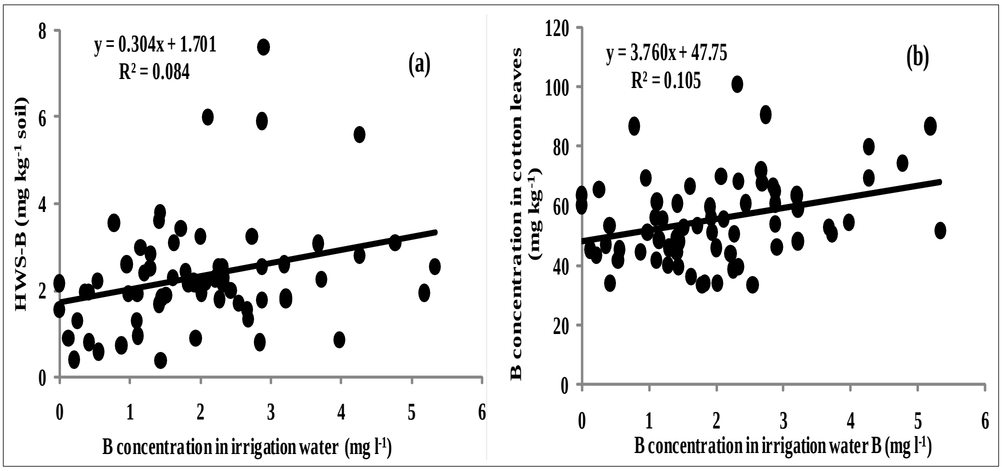

Fig 2: Relationship of B concentration in irrigation water with hot water soluble B in soil (a) and B concentration in cotton leaves (b).

CONCLUSION

The results revealed that though the deficiency symptoms of B did not appear in cotton and wheat, about 18 and 20 per cent of the leaf samples of cotton and wheat, respectively were deficient in B. A considerable amount of B might be added to cotton and wheat through irrigation water. Hence, its computation is necessary before applying to the crops. The B concentration of cotton and wheat crop was highly correlated with the B content in irrigation water and in soil. Thus, B application should be based on chemical analysis of soil, water and tissue analysis of the crop.

Conflict of interest: None.

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