BORON STATUS OF SOILS AS AFFECTED BY DIFFERENT SOIL CHARACTERISTICS–pH, $CaCO_3$, ORGANIC MATTER AND CLAY CONTENTS

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In Pakistan, the soils are mostly developed from calcareous, alluvial and loessial deposits of *late Pleistocene* age located partially on *old river terrace* and relatively on the *channel-levee-remnants*, therefore micronutrients instigate from weathering of rock parent materials and their deficiencies are wide spread because of intensive cultivation and more nutrient uptake than application. This study was started to determine the authentic information about boron status of calcareous soils having alkaline pH and low organic matter (OM) contents under canal and tube well irrigated areas of Punjab. Soil samples were collected from eighty one sites of five districts of Punjab. Soil samples were analyzed for pHs, texture, ECe, total N, Extractable K, Olsen P, $CaCO_3$, OM and 0.05 M HCl extractable B. The textural analysis exhibited that 28 % area had more clay contents and was classified as heavy textured, 42 % had loamy texture while 30 % had sandy or light textured. The results revealed that more B was observed in clay textured soils. In case of pH, 83 % area (68 sites) had pH ≥ 8.00 while 13 sites had pH ranged from 7.50 to 8.00 and only one site has pH < 7.50. Incredibly low OM was observed in surveyed area and it was <1 % in all the 81 samples (100 % area was low in OM). Similarly $CaCO_3$ contents were in the range of 2.14 to 9.72 % and about 92 % area surveyed had $CaCO_3$ contents in the range of 3-10 %. The data regarding B concentration in soil reflected an atrocious depiction of B deficiency in the surveyed soils and exhibited that out of 81 samples, 66 sites (82 %) had B concentration in the range of 0.10 to 0.45 µg g^{-1} and were fall in the deficient range (i.e. <0.50 the critical level) while 12 sites (15 %) having B concentration in the range of 0.46 to 0.55 µg g^{-1} and only 3 samples had B range 0.56-0.91 µg g^{-1}. Correlation analysis exhibited that soil B is positively correlated with OM and clay content of soil while it had strong negative correlation with $CaCO_3$ content and pH.

Key words: Boron, status, calcareous, pH, organic matter, clay, Pakistan.

INTRODUCTION

The economy of Pakistan depends upon agriculture sector either directly or indirectly, and provides food for the constantly mounting population (~160 million currently) (Anonymous, 2007). The country has a total area of 79.6 Mha, with 22.0 Mha cultivated (GoP, 2007). Agriculture contributes 21 % share in GDP and it not only feeds 160 million people but also has an imperative share of raw stuff for industry (textile, food, paper and sugar) (Anonymous, 2007). Plant nutritionists scientifically verified that boron (B) is one of the sixteen elements essential for plant growth but the requisite research and literature regarding exploitation of B in Pakistan is lacking. Boron is implicated in numerous plant functions directly and indirectly as it involves in growth of cells in newly emerging shoot and root while in some plants it is imperative for flowering, pollination, boll formation, seed development and the transport of sugar contained by the plant (Hu and Brown, 1994). The worldwide study on micronutrients status regarding Pakistan reported that 49 % area of Punjab was B deficient (Sillaanpae 1982; Rashid, 2005; 1995, 1996 b; Rashid *et al.,* 1997; Niaz *et al*., 2002). The low B availability to plants is also influenced by dynamic soil properties including organic matter, texture, cultivation, drought, and microbial activity (Mengel and Kirkby, 2001; Goldberg 1993; Wear and Patterson, 1962). Others revealed that B sorption increased due to high calcite in soil and liming diminished the water-soluble B content of soils (Goldberg and Forster, 1991). In our soils, some amount of B is adsorbed on clays or gradually complexed within organic matter (Yermiyaho, 1995; Gu and Lowe, 1990) and to some extent it is precipitated with $CaCO_3$ and is quite unavailable for plant growth (Shorrocks, 1997). Fertilizer efficiency is incredibly low in Pakistan because majority of soils are alkaline in reaction (high pH) and calcareous in nature (Anonymous, 2002). Moreover cotton growers repetitively expressed grievances regarding premature shedding of flowers, bolls and squares from their normal crops and they have no awareness regarding nutrient deficit especially B in their crops. So keeping in view the importance and significance of boron in crop nutrition, this study was initiated to build up the reliable information about B status of soils as affected by different soil properties including alkaline pH, variant $CaCO_3$, clay and low organic matter contents under canal and tube well irrigated areas of Punjab.

MATERIALS AND METHODS

This research was conducted at Institute of Soil & Environmental Sciences (ISES), University of Agriculture, Faisalabad during 2005-2006. Eighty one soil samples were collected from Faisalabad, Jhang, Toba Tek Singh, Sargodha and Sahiwal districts. The soils of surveyed area are developed in calcareous, sandy, silty, loamy and clayey material of late Pleistocene age (>1000 years) alluvium and loess. A dense or compacted layer, known as plough pan or plough sole was present in some soils particularly Lyallpur silt loam, Lyallpur loam, Bhalwal silty clay loam, Bhalwal clay loam and at places in Miranpur silty clay and Pindorian clay loam. The climate of the area is arid to semi arid subtropical, with a mean annual rainfall of 340 mm (13.6 inches) most of which falls during the months of Monsoon (July-August), in the form of high intensity rainstorm and downpours. About 1/3 of the total rain fall is received in winter in the form of low intensity showers of long duration. The hottest months are may and June, with a mean maximum temperature of 103^0F and 106^0 F respectively, with a daily maximum rising to 118^o F at mid-day times. January is the coldest month with a mean minimum temperature of 41^0F. Frost usually occurs for the short spell of 10-25 days in December and January. According to Water and Soil Investigation Division (WASID), WAPDA the survey area falls within the brackish ground water zone (total soluble salts ≥3000 ppm) or very brackish (TSS ≥ 4000 ppm).

Soil Analysis

Composite soil samples were collected from farmer's fields. Soil samples were collected from 0-15 cm soil depth and analyzed for ECe (Rhoades, 1982), pHs (Mclean, 1982), organic matter (Nelson and Sommers, 1982), particle size analysis (Gee and Bauder, 1986), $CaCO_3$ and available B (Bingham, 1982). Boron was extracted by 0.05M HCl (Ponnamperuma *et al.*, 1981) and color was developed by azomethine-H by using *Genesis-5 Spectronic Spectrophotometer* at 420 nm wavelength (Malekani and Cresser, 1998).

Statistical Analysis

Descriptive Statistics (mean, median, mode, standard deviation, skewness and kurtosis) was used for the data analysis. Moreover, multiple regression and correlation between B and soil properties (pH, $CaCO_3$, OM and clay contents) were also performed to the data.

RESULTS AND DISCUSSION

Soil analysis

The descriptive statistical analysis (Table 1) of data showed that soil B concentration exhibited a positive skew, with the mean greater than the median. Soil pH, OM and $CaCO_3$ demonstrated a slight but reckonable negative skew. A relatively diminutive degree of kurtosis was revealed by all properties, with the supreme effect perceived in soil B (4.86) and soil pH (2.55). The coefficients of *skewness and kurtosis* values illustrate the shape of the sample distribution. A *positive skew* indicates asymmetry and irregularity in the distribution, with the elevated data values tailing to the right, and a negative skew represents inferior values tailing left. *Kurtosis* describes the relative size of the distribution's tails. A positive coefficient of kurtosis specifies that the distribution is peaked, and a negative value point out a relatively flat distribution.

Soil extractable (0.05 M HCl) boron concentration

The data regarding B concentration in soil samples reflected an atrocious depiction of B deficiency in the surveyed soils and exhibited that out of 81 samples, 66 sites (82 % area) had B concentration in the range of 0.10 to 0.45 μg g^{-1} and were fall in the deficient range (i.e. B concentration ≤0.50, the critical level), while 12 sites (15 %) having B concentration in the range of 0.46 to 0.55 μg g^{-1} and only 3 samples had B range of 0.56-0.97 µg g^{-1}. The results and pie graph (Fig. 1) demonstrated that the distribution of B concentration of soil (0.05 M HCl extractable) is very low and about 82 % area was B deficient. Highest B concentration (0.97 mg kg^{-1}) was observed at the saline soil where EC_e of soil was high and lowest B (0.11 mg kg^{-1}) was obtained from sandy soils. The mean B concentration is 0.32 mg kg^{-1} with S.D. (0.14) and this low B is due to the high pH of soil and $CaCO_3$ contents which adsorb B and makes it unavailable to go to the soil solution (Table 1).

Soil pH

Mean pH value (8.07, SD = 0.17) was well agreed with mode and median (Table 1), while minimum, maximum and range pH values were 7.45, 8.55 and 1.10, respectively. The data indicated that majority of the area was alkaline in reaction because of high pH values (pH > 7.0).

Table 1. Descriptive statistical analysis of the soil samples collected from the surveyed area

Statistical Parameters	B (mg kg^{-1})	OM (%)	$CaCO_3$ (%)	pH
Mean	0.32	0.62	6.29	8.07
Standard Error	0.02	0.02	0.23	0.02
Median	0.31	0.61	6.47	8.10
Mode	0.23	0.46	6.28	8.10
SD	0.14	0.20	2.09	0.17
Sample Variance	0.02	0.04	4.36	0.03
Kurtosis	4.86	-0.61	-0.90	2.55
Skewness	1.64	-0.04	-0.32	-0.99
Range	0.86	0.84	7.58	1.10
Minimum	0.11	0.15	2.14	7.45
Maximum	0.97	0.99	9.72	8.55
Sum	26.00	50.34	509.05	653.78
Count	81.00	81.00	81.00	81.00
Confidence Level (95.0%)	0.03	0.05	0.46	0.04

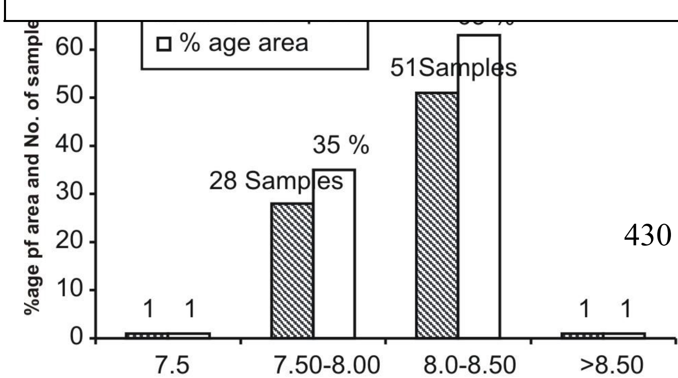

Figure 2. Soil pH distribution in soil samples.

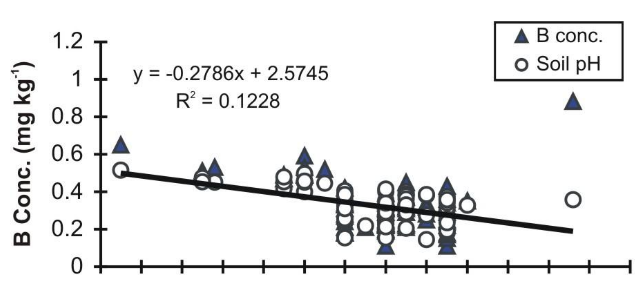

Figure 3. Soil B versus soil pH line fit Plot

It was clear from results (Fig.2) that out of 81 samples, only one had pH 7.45 and 8.55 (1% each), 28

samples had pH range of 7.50-8.00 (35 %) while remaining 51 samples had pH values 8.0-8.50 (63 %). So over all data indicated that 99 % samples had pH > 7.50, which ultimately caused low B availability in soil. An interesting picture exhibited from the data that those soils which had low pH values, their B concentration is increased with decreasing pH trend and vice versa. The correlation (Table 2) value of pH with B is (r, -0.35 at $p<0.05$) and pH with OM is (r, -0.60 at $p<0.05$), while pH is positively correlated with $CaCO_3$ (r, 0.33 at $p<0.05$). Figure 3 illustrated the negative relationship between soil B and pH of soil ($R^2 = 0.13$ at $p<0.05$) which clearly exhibited that as the pH of soil increased, the availability of B decreased. These results were also supported by other researchers and they reported that soluble B content in soil was highly significantly correlated with solution pH (Elrashidi and O'Connor, 1982). B uptake by plants at water soluble B content was greater at lower soil solution pH (Wear and Patterson, 1962). Boron adsorption by soils increased as a function of solution pH in the range of pH 3 to 9 (Lehto, 1995) and decreased in the range of pH 10 to 11.5 (Goldberg and Glaubig, 1986a).

$CaCO_3$

The results revealed that there is strong negative correlation ($r = -0.66$ at $p < 0.05$) between soil available B and $CaCO_3$ contents of soil (Table 2). The adsorption of B on $CaCO_3$ is more which results into less B available to plants in calcareous soils of Pakistan. Moreover, high alkalinity (pH) of soils caused accretion of $CaCO_3$ in our soils and > 72 % area had high $CaCO_3$ contents (Table 3). Figure 4 showed the simple regression analysis of B versus $CaCO_3$ contents and indicated the significance of data while using linear relationship (R^2 = 0.57 at $p < 0.05$). Mean $CaCO_3$ contents were 6.29 % (S.D. = 2.09) having maximum, minimum and range value of 9.72, 2.14 and 7.58, respectively (Table 1). A promising reason for the increase in adsorption of B on $CaCO_3$ is the bonding of B with calcium carbonate ($CaCO_3$). This could be escorted to the precipitation of calcium-borate, substitution of carbon by boron in $CaCO_3$ or simple surface adsorption of B on $CaCO_3$. Similar kind of results was reported by many researchers (Goldberg, 1993; Elrashidi and O'Connor, 1982). Calcium carbonate act as an important B adsorbing surface in calcareous soils and B adsorption was greater on soils having higher $CaCO_3$ content (Goldberg and Forster, 1991). Retention of B on reference calcites increased with increasing solution pH from pH 6 to 9.

Table 2. Correlation between soil B, OM, pH, $CaCO_3$, sand, silt and clay of soil samples analyzed

Soil Characteristics	B	OM	pH	$CaCO_3$	Sand	Silt	Clay
Boron	1						
Organic matter	0.37	1					
Soil pH	-0.35	-0.60	1				
$CaCO_3$	-0.66	-0.33	0.33	1			
Sand	-0.03	-0.14	0.19	-0.02	1		
Silt	-0.05	0.09	-0.23	-0.01	-0.79	1	
Clay	0.10	0.13	-0.05	0.04	-0.74	0.17	1

Table 3. Distributions of $CaCO_3$ in the soil samples of surveyed area

Ranges of $CaCO_3$	No. of samples	% age of surveyed area
< 3.0 %	7	8.6
3-5 %	16	19.8
5-7 %	29	35.8
7-9 %	22	27.2
> 9.0 %	7	8.6
Total	81	100

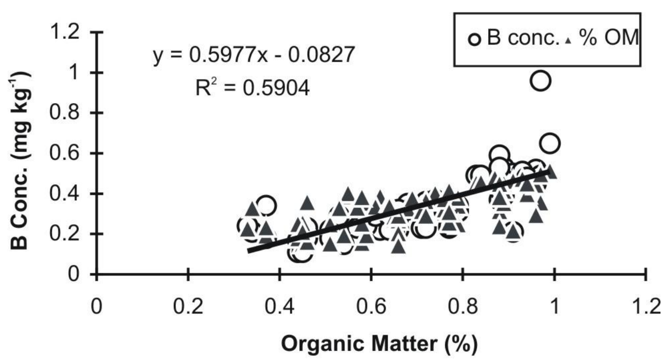

Figure 5. Boron versus OM line fit plot

Organic matter

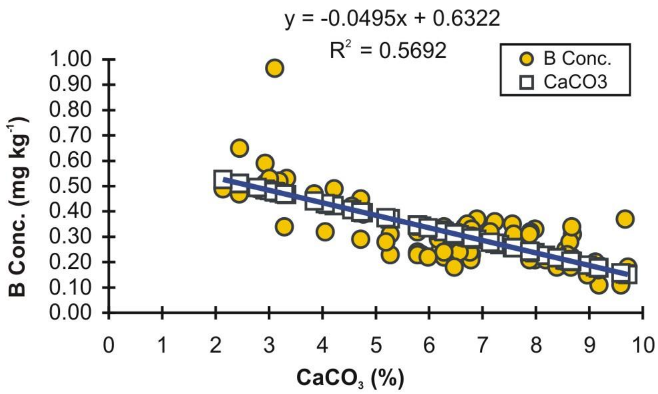

Figure 4. Soil Boron Vs CaCO

Organic matter is an important soil constituent affecting the availability of B. The mean OM contents of all sites were 0.62% (SD = 0.20) with maximum, minimum and range value of 0.99, 0.15 and 0.84 %, respectively (Table 1). Correlation (Table 2) (r = 0.37 at $p < 0.05$) and regression (Fig. 5) ($R^2 = 0.59$ at $p < 0.05$) analysis showed that soil B has positive correlation with OM and with increase in OM content of soil, B concentration augmented as well and this boost might be due to the decomposition of OM (by producing of certain acids like tartaric, oxalic, citric, acetic, formic, fluvic and humic acid) that solublize the unavailable fixed B or adsorbed B in clay or $CaCO_3$. Moreover, some of B is complexed or chealeted with OM content and on decomposition, this B is released into soil solution. OM is considered as the leading source of reserve B because it complexes with B to eradicate it from the soil solution when the levels are high after B fertilization. It then re-supplies the soil solution to sustain ample levels when B is removed by crops or leaching occurred. Since, the surveyed soils were low in OM; consequently these soils necessitate supplementary and episodic B fertilization at diminutive levels of B per acre. These results were also supported by many researchers and their findings concluded that native soil B and hot water extractable B were highly significantly correlated with organic carbon content (Elrashidi and O'Connor, 1982). Soil organic matter adsorbs more B than mineral soil constituents on a weight basis (Gu and Lowe, 1990). Boron adsorption on an organic soil (Lehto, 1995) and composted organic matter increased with increasing pH (Yermiyahu *et al.*, 1995). Adsorption of B on a soil humic acid increased with increasing pH up to a maximum near pH 9, and decreased with increasing pH above 9 (Gu and Lowe, 1990).

Effect of texture on B

The textural analysis exhibited that 28 % area had more clay contents and was classified as fine textured, 42 % had loamy texture while 30 % had sandy or coarse texture (Table 4). The results revealed that more B was observed in clay textured soils. However, available B may be quite low because of the strength by which B is strongly held on clay surfaces or $CaCO_3$. Coarse textured (sandy) soils often restrained less available B than fine textured soils, thus B deficiency frequently arise in areas located in sandy soils (Fleming, 1980). Native B was significantly positively correlated with soil clay content (Elrashidi and O'Connor, 1982). Correlation (Table 2) and regression ($R^2 = 0.009$ at $p < 0.05$) (Fig. 6) analysis exhibited that clay had a positive correlation (r = 10 at $p < 0.05$) while sand and silt had negative correlation (r = -0.03 and -0.05, respectively) with soil B and verified that with rising sand and silt contents, soil B concentration decreased. While in case of clay content of soil (fine textured soils), B is positively correlated with clay and more B concentrations were obtained from the soils where fine textured soils were dominant and clay contents of soil were more than sand and silt.

Table 4. Distribution of area surveyed according to textural classification

Texture	Textural Class	No. of samples	Percent area	Total area
Fine	Clay	8	9.9	
	Clay Loam	15	18.5	28
Medium	Loam	12	14.8	
	Sandy clay loam	12	14.8	
	Silty clay loam	10	12.4	42

Coarse	Sand	2	2.5	
	Loamy sand	8	9.9	
	Sandy loam	14	17.3	30

CONCLUSION

1. High soil pH, intense calcareousness ($CaCO_3$) and scarce organic matter were found in the surveyed area and these soil properties significantly diminished the available B contents of soils of Pakistan.
2. Eighty two percent area was robustly found B deficient.
3. Correlation analysis exhibited that soil B is positively correlated with OM and clay content whilst it had negative correlation with $CaCO_3$ and pH.

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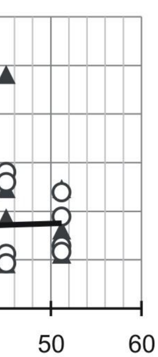

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