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Boron adsorption characteristics in temperate orchard soils of Jammu

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Abstract : Boron (B) adsorption characteristics of soils from apple orchards in Jammu region were studied. Soil samples from 14 representative sites were equilibrated with boric acid solutions of known concentrations (2.5-80 μg/ml B). B was adsorbed by the soils in a manner conforming to the Freundlich and Langmuir equations. The adsorption properties of B in soil as influenced by different physico-chemical properties were also studied. Adsorption increased with soil pH and fineness of soil texture. The adsorption study revealed that organic matter and clay were primarily responsible for retaining added B in all the 14 soils under investigation. Organic carbon, pH and cation-exchange capacity (CEC) positively influenced the adsorption. Freundlich isotherm proved more effective in describing B adsorption as compared to Langmuir equation. Regression models as a function of B application rate and adsorption equation parameters to predict B uptake from applied B, demonstrated the utility of Langmuir and Freundlich equation parameters.

Additional key words : *Langmuir, Freundlich, organic matter, regression, apple*

Introduction

Boron (B) is a trace element essential for the growth of higher plants, but the plant sufficiency range is narrow (Reisenauer *et al.* 1973). Boron deficiency symptoms in plants are often observed in areas of plentiful rainfall because of small soil solution B concentrations and large amounts of B leaching (Keren and Bingham, 1985). Moreover, B deficiency often occurs on sandy soils because of their low B adsorption capacity. Hilly apple growing soils of temperate regions of Jammu are mostly dominated by Lithic or Typic Udorthents (Sidhu *et al.* 1999). These soils have already been reported to be deficient in B (Mondal 2002). Detailed quantification of B adsorption reactions is necessary to understand the fate and transport of B in soils. This knowledge is essential for determining appropriate applications of B fertilizers, management practices to improve B availability to apple plant, which is sensitive to B deficiency. Since plants respond only to solution B (Keren *et al.* 1985), adsorption sites play an important role in managing B concentrations. Adsorption sites on organic matter, oxide minerals, clay minerals and carbonates act as sources and sinks for B. Adsorbed B is neither directly available nor toxic to plants (Keren *et al.* 1985). Thus, the adsorption complex plays a critical role in controlling soil solution B concentrations.

Adsorption of B on soil constituents has been described by various empirical and chemical modeling approaches viz., Langmuir and Freundlich adsorption isotherm equations which are valid for the particular conditions of the measurement (Goldberg 1993). Even so, their constants have often been used to obtain important information on B availability and on the soil sorption capacity and intensity (Elrashidi and O'Connor 1982; Nicholaichuk *et al.* 1988; Marzadori *et al.* 1991). The objectives of this study were to evaluate B adsorption in 14 representative apple growing soils in temperate regions of Jammu of Jammu & Kashmir and to correlate these values with chemical and physical soil attributes through simple correlations and multiple regression analysis. *Langmuir* and *Freundlich* models were tested and the boron adsorp-tion parameters were correlated with soil attributes.

Materials and Methods

Soil samples (0-15 cm) were collected from 14 apple orchards of various locations representing temperate region of district Doda (in Jammu). The study area is located between 32°17' to 34°11'N latitude and 75°35' to 76°60' E longitude with altitude ranging between 1247m to 1850 m above MSL. The mean annual temperature is 15.6 °C with maximum of 34.0 °C and a minimum of (-) 5 °C during June and January, respectively. The mean annual rainfall is 350mm, 70% of which comes during winter and spring months during December to May. The mean summer and winter soil temperatures are 13.5°C and 3.7°C, respectively. The physico-chemical properties and available B of soils were determined following standard procedures. 10 g of each of the 14 representative soils was incubated with 0.02*M* $CaCl_2$ solution containing 0, 2.5, 5, 10, 20, 40 and 80μg ml^{-1} B and equilibrated for 24 hours at 25±1°C with occasional shaking. After attaining equilibrium, the B content of equilibrium solution obtained after filtration, was determined with spectrophotometer following Azomethine-H method as suggested by Parker and Gardner (1981). The amount of boron adsorbed was determined from the difference between the amount of boron added initially and that remaining in equilibrium solution. Data pertaining to the adsorption of boron was fitted to the Langmuir and Freundlich adsorption isotherm equations as follows:

Langmuir equation : $$\frac{C}{x/m} = \frac{1}{Kb} + \frac{C}{b}$$

Freundlich equation : $$\log x/m = 1/n \log C + \log K_f$$

Where,

C = equilibrium concentration of boron (μg ml^{-1})
x/m = amount of boron adsorbed as μg g^{-1} of soil
K = bonding energy related constant (L mg^{-1})
b = absorption maxima (μg g^{-1})
n and K_f are the Freundlich constant.

From linear plot of $\frac{C}{x/m}$ versus C, adsorption maxima were calculated as the inverse of the slope and the constant related to bonding energy was determined as slope/interception in Langmuir adsorption isotherm.

Plot of *log* x/m versus *log C* following Freundlich equation the slope *1/n*, rate of adsorption, and *log K*, the extent of adsorption, were determined.

Results and Discussion

The chemical and physical properties of the soils are given in table 1. Soils were generally light in texture, medium to high in organic matter, acidic to neutral in reaction, non-saline and low in available B.

B adsorption was described well with both Langmuir and Freundlich models over our range of B concentrations (0 to 80 μg B mL^{-1}) for all 14 soils (Fig.1). These results were expected up to 30 μg B mL^{-1}, since boron sorption data deviate from the *Langmuir* model only in higher B concentrations as explained by Evans and Sparks (1983). Nevertheless, the lower concentrations used in this work conform to practical boron application rates. However, in the apple growing Jammu region, having a humid climate, deficiencies are prevalent. It is because of the fact that B remains in non- ionic form [B $(OH)_3^0$] in normal pH of humid soil, which is susceptible to leaching loss (Gupta *et al.* 1985).

Table 1. Some chemical and physical attributes from representative apple growing temperate areas of Jammu

S.No	Locations	pH (1:2.5)	EC (dS m^{-1})	OC %	CEC [cmol $(p^+)kg^{-1}$]	$CaCO_3$	Sand	Silt	Clay	Silt + Clay	Available Boron ($mg\ kg^{-1}$)
						%					
1.	Sarna - 1	6.9	0.02	1.71	7.78	0.31	48	37	5.9	42	0.72
2.	Sarna - 2	6.8	0.07	1.11	16.37	0.54	56	33	11.6	44	0.35
3.	Sarna - 3	6.8	0.01	1.20	21.44	0.51	68	20	12.6	32	0.43
4.	Sartingle -1	6.2	0.07	2.07	8.58	0.46	40	46	6.8	52	1.21
5.	Sartingle - 2	7.6	0.02	1.94	26.43	0.28	36	38	26.6	64	1.07
6.	Sartingle - 3	5.1	0.01	1.50	12.83	0.41	41	39	20.1	59	0.69
7.	Nalthi - 1	6.2	0.21	2.88	10.37	0.16	41	47	6.5	53	1.07
8.	Nalthi - 2	5.7	0.01	1.12	23.98	0.53	41	44	15.6	59	0.36
9.	Nalthi - 3	6.1	0.02	1.14	19.90	0.52	52	38	10.6	48	0.38
10.	Sungali - 1	6.3	0.01	0.60	11.33	0.30	46	41	12.2	53	0.58
11.	Sungali - 2	7.3	0.02	1.38	15.86	0.45	48	37	15.6	52	0.59
12.	Chinta	7.2	0.02	1.67	12.06	0.53	69	24	12.5	36	0.84
13	Gatha	6.9	0.07	1.42	12.09	0.52	73	12	12.6	25	0.62
14.	Kahi	6.5	0.02	1.02	14.11	0.72	43	40	13.6	53	0.27
	Mean	6.5	0.05	1.50	15.22	0.43	50	35	13.1	50	0.66
Range	Minimum	5.1	0.01	0.60	7.78	0.16	36	12	5.9	26	0.27
	Maximum	7.6	0.21	2.88	26.43	0.72	73	47	26.6	64	1.21

B adsorption maximum (b) estimated by Langmuir isotherm (Ad_{max}) varied from 0.33 to 4.07 mg kg^{-1} soil (Table 2). These values are generally similar to those found by Prasad (1978) and Mezuman and Keren (1981) but are lower than the values reported by Nicholaichuk *et al.* (1988). Adsorption maximum decreased based on the differences in chemical and physical attributes of the soils, mainly the decreasing organic matter, clay, silt, sand, $CaCO_3$ and oxide contents. Highest values for maximum adsorption were found in the clayey soils (Sartingle - 2). The bonding energy related constant (K), varied from 0.012 L mg^{-1} in Sartingle-2 soil and a maximum of 0.636 L mg^{-1} in Kahi soil, with a mean value of 0.140 L mg^{-1}. This indicates that the affinity of soil for B varied with its physico-chemical properties. The Freundlich constant *1/n* (rate of adsorption) ranged from 1.12 to 1.69 with a mean value of 1.39. The Freundlich constant *log* K (extent of adsorption) varied from 1.330 to 2.230 with a mean value of 1.590 mg g^{-1}, following the tendency of higher values in fine-textured soils (Mead, 1981, Elrashidi and O'Connor 1982 and Nicholaichuk *et al.* 1988). The maximum buffering capacity (MBC) of the soils varied from 0.016 to 0.235 with a mean value of 0.090 L kg^{-1}. Therefore, it appears that these apple growing soils of Jammu were low in B adsorption capacity.

The simple linear correlation coefficient values between different adsorption constants and soil physico-chemical properties are given in table 3. The Ad_{max} and clay content was highly significant ($r=0.677^{**}$). The clay proportions varied due to differential slope of the studied area. Therefore, the comparison based only on clay contents was undertaken (Keren and Bingham, 1985). Organic matter, CEC, silt+clay and pH were positively correlated with Ad_{max} as well. The correlation coefficients varied from (-) 0.248 ($CaCO_3$) to 0.677^{**} (clay). There was a significant negative correlation ($r=-0.782^{**}$ and $r=-0.580^{*}$) between Freundlich constant *log K* (extent of adsorption) and clay+silt, and

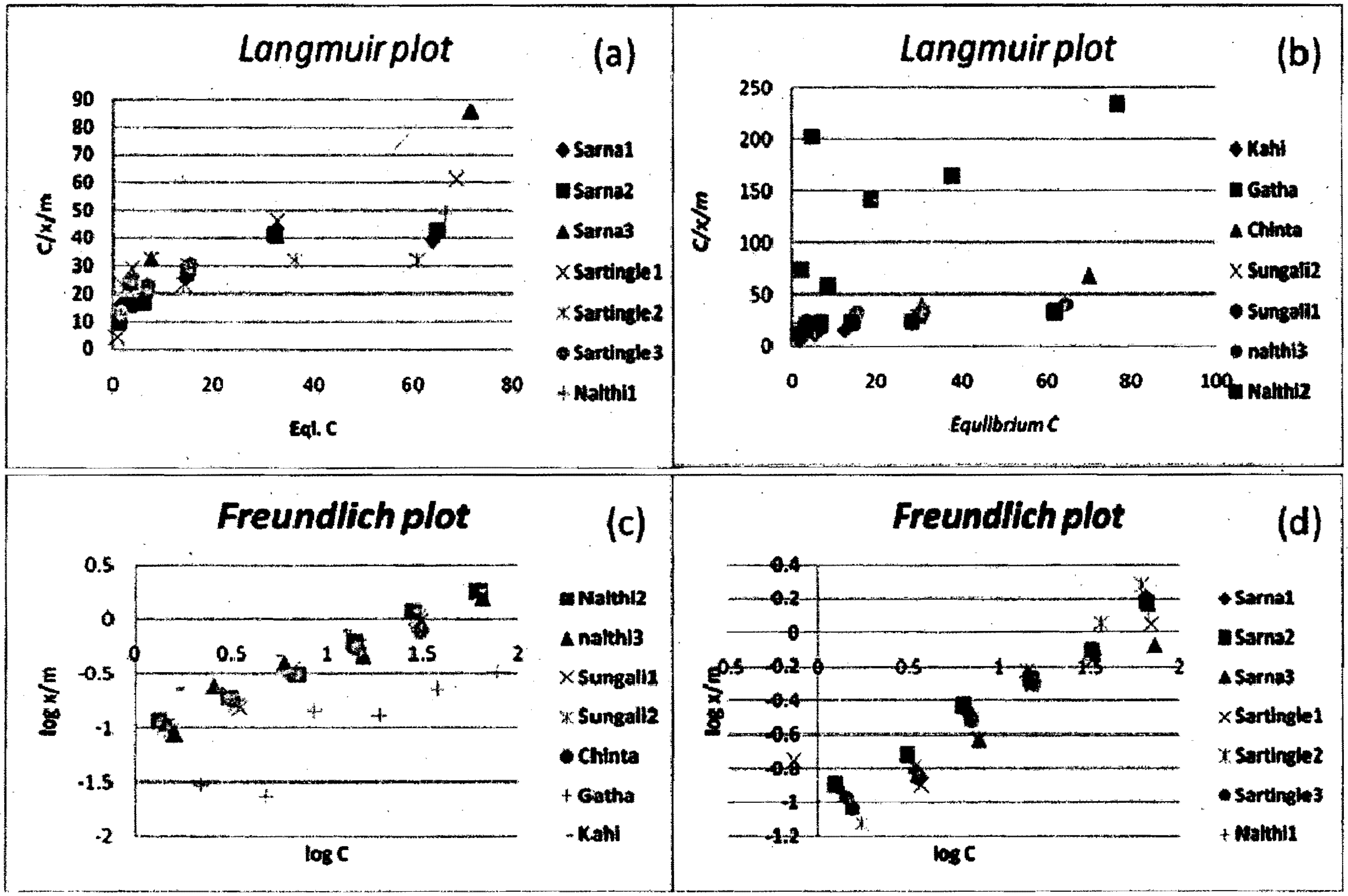

Fig. 1. Langmuir (a, b) and Freundlich (c, d) adsorption isotherms showing Boron adsorption in different soils

Table 2. Langmuir and Freundlich constants

Sl No.	Locations	Langmuir			Freundlich	
		Ad_{max} b $mgkg^{-1}$	Bonding Energy K, L mg^{-1}	MBC (bxK)	Rate of Adsorption (1/n)	Extent of Adsorption (*log K*)
1.	Sarna - 1	0.80	0.085	0.068	1.31	1.546
2.	Sarna - 2	0.83	0.123	0.102	1.61	1.576
3.	Sarna - 3	0.38	0.199	0.076	1.51	1.762
4.	Sartingle -1	1.22	0.127	0.155	1.69	1.721
5.	Sartingle - 2	4.07	0.012	0.049	1.13	1.445
6.	Sartingle - 3	3.00	0.022	0.066	1.19	1.454
7.	Nalthi - 13	1.13	0.062	0.070	1.51	1.648
8.	Nalthi - 2	0.52	0.207	0.108	1.32	1.426
9.	Nalthi - 3	1.30	0.046	0.060	1.38	1.494
10.	Sungali - 1	0.33	0.284	0.094	1.28	1.473
11.	Sungali - 2	3.61	0.015	0.054	1.24	1.464
12.	Chinta	1.30	0.055	0.072	1.57	1.632
13	Gatha	0.37	0.043	0.016	1.12	2.230
14.	Kahi	0.37	0.636	0.235	1.56	1.330

between *1/n* (rate of adsorption) and clay content of soils, respectively. Rest of correlation coefficients were non significant.

In the multiple regression analysis (table 4), B maximum adsorption was a function of clay (%), organic matter (%), EC, silt (%) and pH. Clay and

Table 3: Simple correlation coefficients

Soil Properties	Langmuir adsorption constants			Freundlich adsorption constants	
	Adsorption maxima	Bonding energy	MBC (bxK)	Extent of adsorption (log K)	Rate of Adsorption (1/n)
pH	0.218	-0.139	-0.238	0.207	-0.049
EC	-0.230	-0.120	-0.024	0.284	0.269
OC	0.299	-0.454	-0.198	0.207	0.148
CEC	0.303	-0.039	-0.169	0.194	-0.146
Clay	0.677**	-0.011	-0.191	-0.300	-0.580*
Clay + Silt	0.522	0.099	0.290	-0.782**	-0.145
$CaCO_3$	-0.248	0.434	0.222	0.017	-0.019

**Significant at the 0.05 level; **Significant at the 0.01 level;*

Table 4: Multiple regression equations for Langmuir adsorption maxima (b)

Y =	Intercept/ Constant	X_1	X_2	X_3	X_4	X_5	R^2 x 100
1	-5.540	0.640*	0.560	-0.297	0.259	0.186	58.7*
2	-3.084	0.653*	0.625	-0.333	0.169		58.1*
3	-2.455	0.652*	0.659*	-0.325			58.0**
4	-2.359	0.759**	0.439*				56.9**

Where; X_1= clay (%), X_2 = OC (%), X_3 = EC, X_4 = silt (%), X_5 = pH organic matter practically accounted wholly for the variation of B adsorption maximum (56.9 %), confirming the tendency observed in simple correlation and supporting its importance on B adsorption in soils. In the multiple regression analysis (table 5), maximum buffering capacity (MBC) of B was a function of clay (%), $CaCO_3$ (%), sand (%), available B, OC, EC. However, clay, $CaCO_3$ and sand accounted to large extent for the variation of B adsorption maximum (65.2 %).

Table 5: Multiple regression equations for maximum buffering capacity (MBC)

Y =	Intercept/ Constant	X_1	X_2	X_3	X_4	X_5	X_6	R^2 x 100
1	0.149	-0.338	0.910*	-0.748**	0.367	0.241	0.398	56.9*
2	0.155	-0.406	0.861**	-0.743**	0.258	-0.170		59.5*
3	0.140	-0.378	0.871**	-0.737**	0.127			62.7*
4	0.170	-0.381*	0.791**	-0.744**				65.2**

Where; X_1 = clay (%), X_2 = $CaCO_3$ (%), X_3 = sand (%), X_4 = available B, X_5 = OC, X_6 = EC

Table 6: Multiple regression equations for Freundlich 1/n

Y =	Intercept/ Constant	X_1	X_2	X_3	X_4	X_5	R^2 x 100
1	-1.488	0.419	1.659*	1.497*	0.699*	0.225	52.7*
2	-1.752	0.494	1.864**	1.712**	0.636		53.4*

Where; X_1 = available B, X_2 = silt (%), X_3 = sand (%), X_4 = $CaCO_3$ (%), X_5 = EC

In the multiple regression analysis (table 6). Freundlich 1/n, the rate of adsorption was a function of available B, silt (%), sand (%), $CaCO_3$ (%) and EC. Available B, silt (%), sand (%) and $CaCO_3$ (%) accounted to a great extent for the variation of boron adsorption maximum (53.4 %), confirming the tendency observed in simple correlation and supporting its importance on boron adsorption in soils.

Soils with higher clay and organic matter content adsorbed higher contents of B than medium textured soils containing low organic matter. Boron deficiency has been observed in soils with high organic matter contents (Hue *et al.* 1988; Mascarenhas *et al.* 1988; Liu *et al.* 1989; Valk *et al.* 1989). This deficiency was related to the high affinity of organic matter for B (Yermiyaho *et al.* 1988, Liu *et al.* 1989). The positive correlation between soil organic matter content and B adsorption (Elrashidi and O'Connor, 1982; Hue *et al.* 1988) supports this hypothesis. Though the role of organic matter in B distribution between the liquid and solid phases of soils is not yet fully understood, the correlation with clay was highly significant (r=0.677**). In the multiple regression analysis, the adsorption maxima of boron was a function of clay, organic carbon, EC, silt and pH of the soils. Clay and organic matter content accounted for 56.9 per cent of the variation of the adsorption maxima values of boron. The inclusion in the model of EC, silt and pH made the determination coefficient increase to approximately 58.7 per cent.

Conclusion

Low B adsorption capacity could be one of the possible reasons for deficiency of B in the studied soils. Application and maintenance of sufficient organic manure in these soils would be beneficial for apple with respect to B availability

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